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LANDSAT-4 TO GROUND STATION INTERFACE DESCRIPTION

REVISION 6

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

LANDSAT-4 TO GROUND STATION INTERFACE DESCRIPTION

REVISION 6

February 1983

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

REVISION PAGE

REVISION	DATE	BY	DESCRIPTION	APPROVED
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Revision 2	5/1981			W. Webb
Revision 3	10/1981		As indicated by vertical black bars marked Rev 3 in the page margins of Revision 3.	W. Webb
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Revision 5	8/1982		Revisions are indicated by black bars in the page margins.	W. Webb
Revision 6	2/1983		Revisions are indicated by black bars* in the page margins.	W. Webb

*Note that the black bars in the page margins are effective only for current revisions and change notices.

PREFACE

Revision 6 of the Landsat-4 to Ground Station Interface Description updates Revision 5 of the document published in August 1982.

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ACRONYMS AND ABBREVIATIONS

ACS	Attitude control system
A/D	Analog to Digital
ADS	Angular displacement sensor
ADSA	Angular displacement sensor assembly
BCD	Binary-coded decimal
BER	Bit error rate
BIφ-M	Biphase mark
BPSK	Biphase-shift key
Cal	Calibration or calibrate
CCT	Computer-compatible tape
CMD	Command
CU	Control Unit
dB	Decibel
dBW	Power in decibels, referenced to 1 watt
DEMUX	Demultiplexer
Domsat	Domestic Communications Satellite
DPU	Data processing unit
DRIRU	Direct readout infrared radiometer unit
ECI	Earth centered inertial
EOL	End of line
EP	Euler parameter
EROS	Earth Resources Observation System
FPA	Focal plane assembly
FS	Flight segment
GMT	Greenwich mean time
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
HDT	High-density tape
IC	Internal calibration
ID	Identification
IFOV	Instantaneous field of view
IIRV	Improved Interrange Vector
IRU	Inertial reference unit
kbps	Kilobits per second
L/F	Low frequency
LGSID	Landsat-4 to Ground Station Interface Description
LGSOWG	Landsat Ground Station Operations Working Group
LSB	Least significant bit

ACRONYMS AND ABBREVIATIONS (Continued)

Mbps	Megabits per second
MFID	Minor-frame Identification
MHz	Megahertz
MMS	Multimission Modular Spacecraft
MNFS	Minor-frame synchronization
MSB	Most significant bit
msec	Millisecond
MSS	Multispectral Scanner
MUX	Multiplexer
NASA	National Aeronautics and Space Administration
NETD	Noise equivalent temperature difference
NRZ	Nonreturn to zero
NRZ-L	Nonreturn to zero level
NRZ-M	Nonreturn to zero mark
OBC	Onboard computer
OCC	Operations Control Center
PCD	Payload correction data
PCM	Pulse-code modulation
PDU	Power distribution unit
PF	Protoflight
PM	Phase modulated
PN	Pseudonoise
PN	Not PN
PSK	Phase-shift keyed
rad	Radian
RIU	Remote interface unit
rms	Root mean square
SAM	Scan angle monitor
SLC	Scan line corrector
SLS	Scan line start
SMA	Scan mirror assembly
SME	Scan mirror electronics
S/N	Signal to noise
S/NR	Signal-to-noise ratio
TBD	To be determined
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TGS	Transportable Ground Station
TLM	Telemetry
TM	Thematic mapper
TWT	Traveling wave tube
TWX	Teletype message

ACRONYMS AND ABBREVIATIONS (Continued)

UQPSK	Unbalanced quadrature phase-shift keyed
UTC	Universal Time, Coordinated

LANDSAT-4 TO GROUND STATION
INTERFACE DESCRIPTION

1. LANDSAT-4 MISSION OVERVIEW

1.1 FLIGHT SEGMENT

Figure 1 is an illustration of the components of the Landsat-4 flight segment.

1.2 ORBIT

The Landsat-4 orbit is defined as follows:

Altitude	705.3 km
Inclination	98.2 degrees
Repeat cycle	16 days
Orbits per cycle	233
Ground trace spacing at Equator	172.0 km
Sidelap at Equator	7.6 percent
Descending node time	0930 to 1000 hours
Nodal period	5933.0472 seconds

The value of 705.3 for the Landsat-4 orbit agrees with the altitude over the Earth's Equator (h_e) that satisfies a Keplerian period (P) corresponding to the design nodal period. The 705.3-km altitude is not intended for use in detailed orbital analyses because it does not precisely represent the actual Landsat-4 altitude at the Equator.

a is altitude measured from the center of the Earth.

$$P = 2\pi\sqrt{\frac{a^3}{\mu}} \qquad P = 5933.0472 \text{ sec; } \mu = 398601.2 \frac{\text{km}^3}{\text{sec}^2}.$$

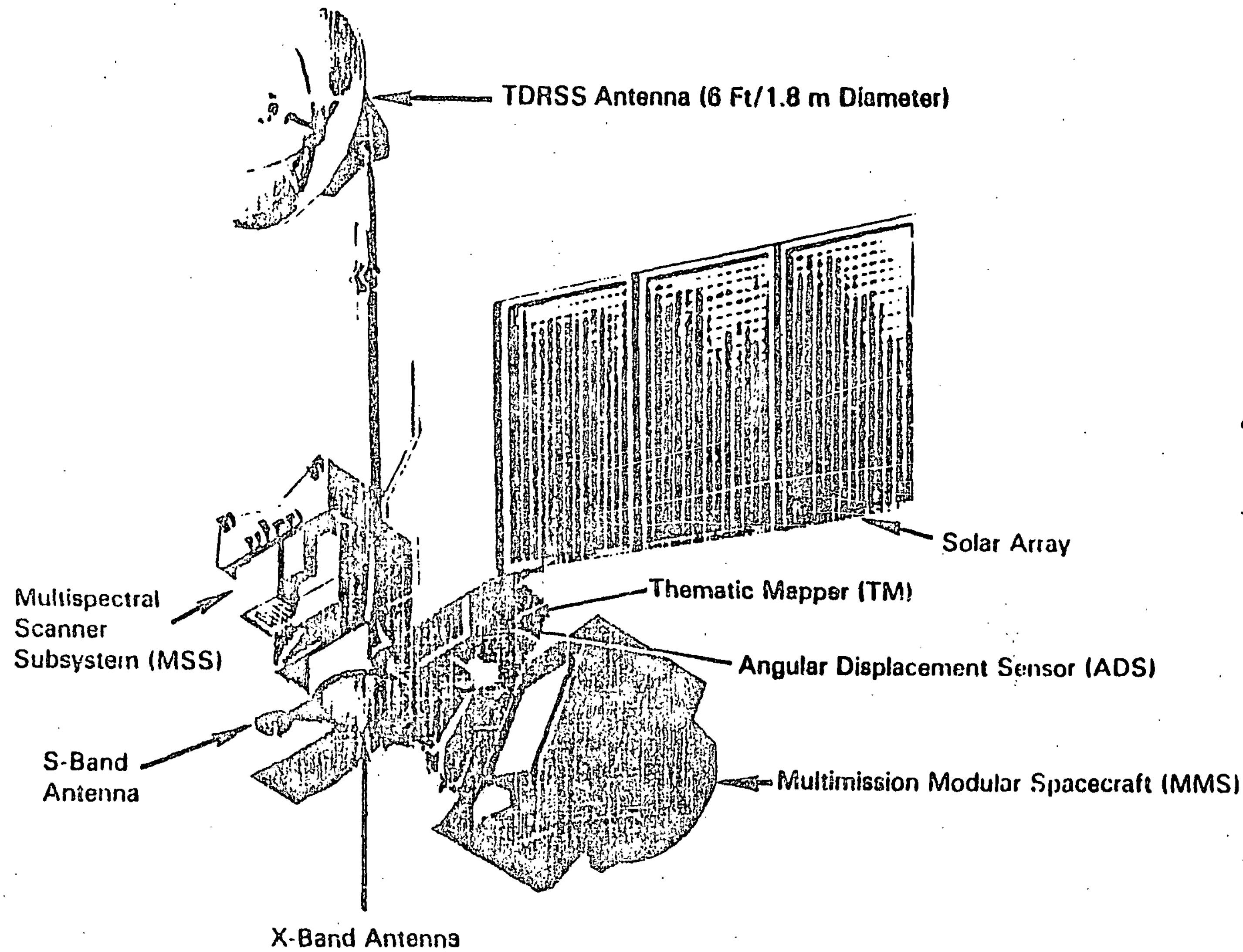

Figure 1. Landsat-4 Flight Segment

$a = 7083.465$ km $r_e = 6378.165$ km.

$h_e = a - r_e = 705.3$ km.

Figure 2 shows the Landsat-4 orbit for the 16-day period. Maps and information regarding nominal ground track and scene-center locations for Landsat-4 will be available from the Earth Resources Observation System (EROS) Data Center, Sioux Falls, South Dakota.

1.3 FUNCTION OF LANDSAT-4 ATTITUDE CONTROL SYSTEM

The Landsat-4 spacecraft attitude control system (ACS) orients the spacecraft relative to a desired target. The central control system element is an onboard computer (OBC) that processes all sensor-derived information and, in conjunction with various types of stored information, generates the appropriate control signals to operate the spacecraft reaction control devices. The Landsat-4 reference sensor system consists of coarse Sun sensors, an Earth sensor (for safe-hold only), an inertial reference unit (IRU), a pair of fixed-head star trackers, and a three-axis magnetometer. All sensor outputs are transferred to the OBC in addition to being downlinked in telemetry. The OBC processes the sensory inputs and derives the control equipment commands. The primary attitude reference is derived from the IRU. The IRU bias drift and scale factor errors are computed within the OBC through use of known target stars. A 1-sigma pointing accuracy of 0.01 degree is expected from this system.

1.4 COMMUNICATIONS

Figure 3 shows the overall data flow from Landsat-4. Foreign ground stations will receive data by X- and S-band links. For more information concerning these data transmissions, refer to Section 9.

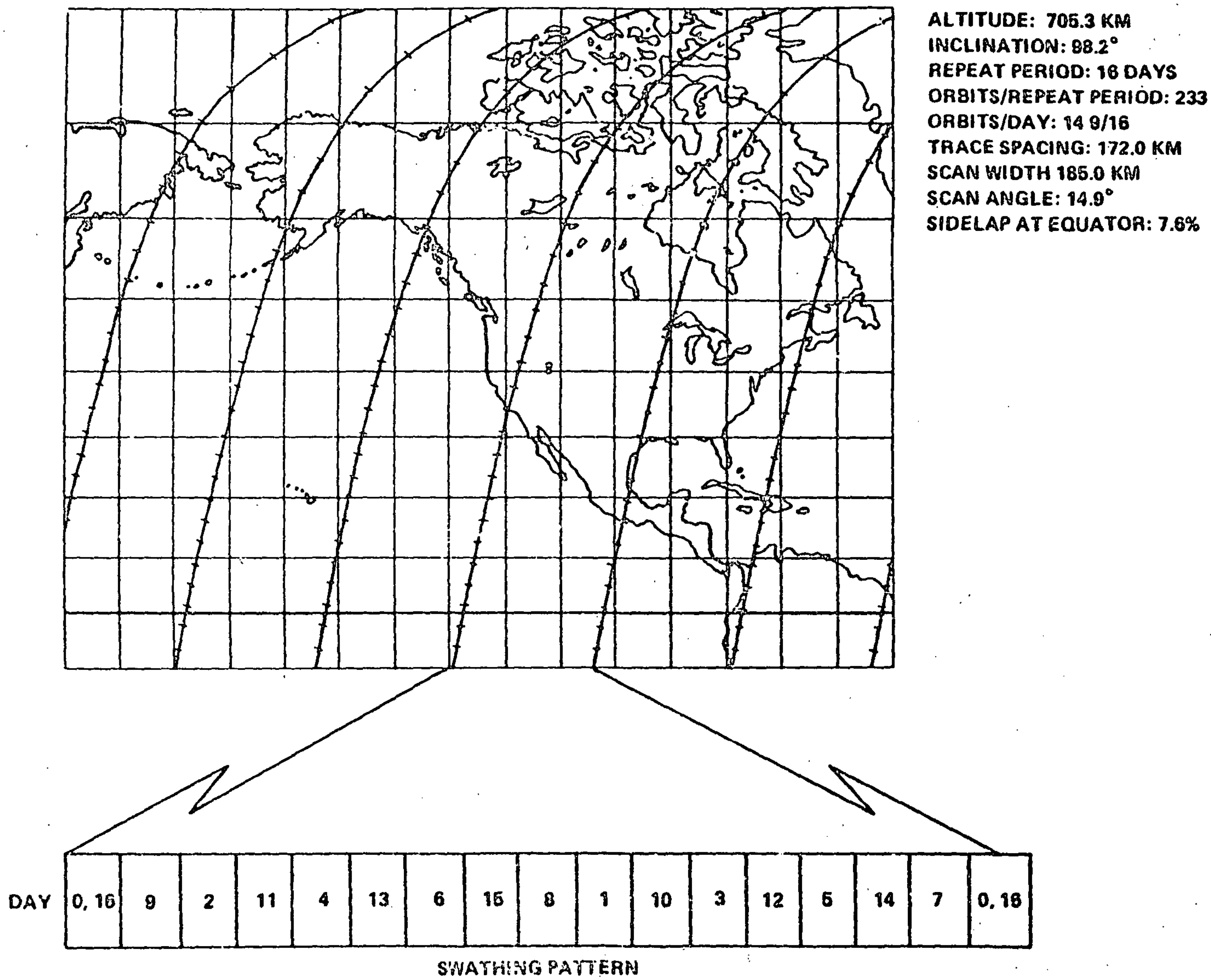

Figure 2. Swathing Pattern for One Satellite (16-Day Coverage)

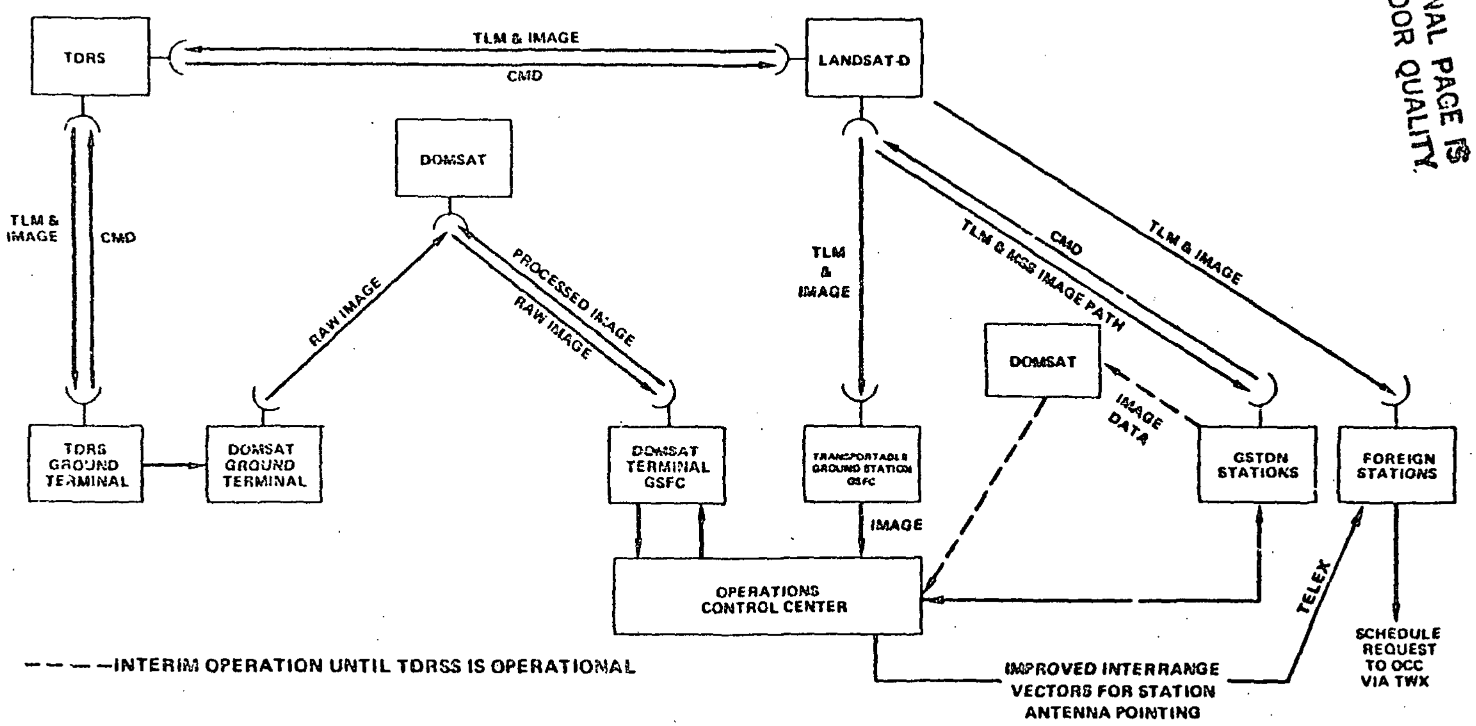

Figure 3. Landsat-4 Overall Data Flow

1.5 NASA/GODDARD SPACE FLIGHT CENTER (GSFC) LANDSAT-4 USER PRODUCT SPECIFICATIONS

a. NASA/GSFC intends to maintain the Landsat-4 Data Management System MSS partially processed output high-density tape (HDT-A) format compatible with the Landsat-3 format family currently in use within the GSFC/Image Processing Facility.

b. MSS user photographic and computer-compatible tape (CCT) products will not be produced by GSFC. The EROS Data Center will be responsible for producing these user products.

c. The TM high-density tape (HDT), CCT, and photographic output product formats have not been defined. However, plans are being made to conform the formats as closely as possible to the generic structure of the HDT and photographic products currently being used for Landsats-2 and -3. GSFC intends to use the Martin Marietta Model MH2879-L high-data-rate recorders and the Goodyear Landsat-4 high-resolution film recording system.

Additional product information should be obtained from the EROS Data Center, Sioux Falls, South Dakota.

2. ATTITUDE AND EPHEMERIS DATA

NASA/GSFC plans to provide attitude and ephemeris data for use in processing image data to Landsat Ground Station Operations Working Group (LGSOWG) members on a routine basis within the telemetry 8 kbps S-band downlink and TM video data.

The ephemeris data, which are provided in the form of orbital-state vectors, will be derived by the spacecraft OBC from uplinked predicted ephemeris data. The accuracy of these data is presented in Table 1 and the content and data format are described in Section 5. The ephemeris data provided within the telemetry S-band downlink and TM video data will normally be between 1 and 2 days after tracking data cutoff. Onboard ephemeris processing by the OBC does not introduce any significant degradation to the accuracies defined in Table 1.

Table 1
Ephemeris Location Accuracy
(1 sigma)

Source	Position/Location Accuracy (meters) (days from tracking cutoff)		
	1	2	3
Predicted-fit ephemeris	250	500	1000

Landsat-4 pointing accuracy will be 0.01 degree (1 sigma). Pointing, ephemeris, alignment of the TM to the pointed axis, and timing errors will result in positional accuracy of the imagery with systematic correction only (no use of ground control points) as summarized below:

Error Source	Cross Track (Meters 1σ)	Along Track (Meters 1σ)
Ephemeris	100	500
Time	N/A	80
Attitude	123	123
Alignment	427	855
Total (root-sum-square)	455	1001

The altitude of the Landsat-4 orbit, considering both orbit eccentricity and the Earth's figure, will vary between about 696 and 741 kilometers. Maximum altitudes will occur over the North and South Poles and minimum altitudes will occur over equatorial regions.

The Landsat-4 ACS-pointed axis is defined as the line of sight from the spacecraft of the geocenter (i.e., the origin of the Earth-centered inertial true-of-date coordinate system). This is also the nominal alignment axis for the optical axes of both the TM and the MSS. Detailed alignment data are provided in Appendix F.

3. NAVIGATIONAL DATA

NASA plans to provide improved interrange vectors (I^2RV) by Telex, which allow proper pointing of ground station antenna for acquisition of satellite data signals. These vectors will be provided daily, at least 24 hours before becoming effective. The I^2RV message is described in Appendix D. Orbital element and state vector data are available from NASA as an alternative to I^2RV messages until the capability to accept I^2RV data is implemented by LGSOWG members.

4. MULTISPECTRAL SCANNER SPECIFICATIONS

4.1 MULTISPECTRAL SCANNER RADIOMETRIC SPECIFICATIONS

4.1.1 Spectral Bands

The MSS operates in four spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.5 to 0.6 micrometers
b. Band 2--0.6 to 0.7 micrometers
c. Band 3--0.7 to 0.8 micrometers
d. Band 4--0.8 to 1.1 micrometers

4.1.2 MSS Detectors

The MSS uses the following detectors in each spectral band:

a. Band 1--Photomultiplier tube (six each)
b. Band 2--Photomultiplier tube (six each)
c. Band 3--Photomultiplier tube (six each)
d. Band 4--Silicon photodiode (six each)

4.1.3 MSS Radiance/Signal Range

The scanner provides video signals that are accurately related to radiance values in each spectral band. The maximum radiance levels for Bands 1 through 4 are:

Band	Maximum Radiance 10^{-4} watts cm^{-2} $ster^{-1}$
1	24.8
2	20.0
3	17.6
4	46.0

NASA has no plans to acquire Sun calibration data for the MSS.

4.1.4 MSS Quantization

Each sample is encoded into a 6-bit word.

4.1.5 MSS Signal-to-Noise Ratio (SNR)

The ratio of output signal level to root mean square (rms) noise input radiance for the scanner and multiplexer is as defined in Table 2 when the multiplexer samples are in the linear mode. When the multiplexer compresses signals from Bands 1, 2, and 3, the SNR's are as defined in Table 3.

Table 2
Linear Mode

	Band			
	1	2	3	4
High-radiance level:				
Minimum system signal-to-noise (S/N) output (after analog to digital (A/D) conversion)	89	73	50	104
1/2 high-radiance level:				
Minimum system S/N output (after A/D conversion)	54	46	33	54

Table 3
Compression Mode

	Band		
	1	2	3
High-radiance level:			
Minimum system S/N output (after A/D conversion)	75	65	47
1/2 high-radiance level:			
Minimum system S/N output (after A/D conversion)	43	38	30

4.2 MSS SCANNING MIRROR CHARACTERISTICS

4.2.1 MSS Geometric Accuracy

The Landsat-4 MSS scan mirror is supported by two flex pivots that exert a restoring torque on the mirror. The torque is zero at approximately the center of scan. Bumpers are provided at the two ends of scan to reverse the mirror angular velocity. During the "active" scan (west to east in the spacecraft descending

node) when video data are collected, the mirror is essentially torque-free except for the flex-pivot torque. During the reverse or back-scan, a torque motor applies torque to restore the system energy lost during the previous scan cycle. The mirror inertia is approximately 0.0077 slug-ft^2 and the combined spring constant of the flex pivots is approximately 4707 ft-lb per radian.

4.2.2 Scan Mirror Assembly

Sensor ground coverage perpendicular to the satellite track is accomplished by means of a flat scanning mirror oriented at 45 degrees with respect to the scene that scans about the X-axis. The following parameters define this scan mirror assembly system:

a. Scan frequency: 13.62 Hz $\pm$0.01 percent

b. Scan angle across scene: 14.90 $\pm$0.06 degrees or 0.26 $\pm$0.001 radian

c. Timing format (Figure A-2)

d. Active scan period: 32.75 $\pm$1.25 milliseconds

4.2.3 Geometric Fidelity

Geometric fidelity shall be defined by:

a. Lines per scan (scanned simultaneously)--Band 1 through Band 4: 6

b. Scan-to-scan line-length variation--42.0 μr, rms over 100 scans (the variation will be larger when operated simultaneously with the TM instrument)

c. Optical centerline variations--Less than 1 percent of full scan

d. Scan repeatability--Scan angle versus time is repeatable within 24 μr, rms over 100 scans after line-length correction

e. Scan nonlinearity--For the linear portion of the forward scan, the repeatable scan rate deviates by less than +2.4, -5.0 percent from the mean scan rate.

4.3 MSS INTERNAL CALIBRATION

There are provisions in the MSS for internal calibration.

4.3.1 Bands 1 through 4 Internal Calibration

The internal calibration is provided on every other mirror scan cycle (major frame). Data on the alternate cycles are black level (dc restore in Band 4). A redundant source and varying neutral density filter will generate appropriate radiant levels and spectral distribution to provide internal calibration for Bands 1 through 4. The internal calibration for Bands 1 through 4 consists of a decreasing gray optical wedge (ramp calibrate) input of 10.2 ±2 milliseconds duration that occurs 42.8 ±2 milliseconds after line-start code (nominally 11 milliseconds after end-of-line code). Preflight gray-wedge test data will be supplied to the Landsat-4 ground stations for all modes of operation. A typical gray-wedge calibration curve is shown in Figure 4. The middle two bits of the binary words are inverted as is the case for all video data.

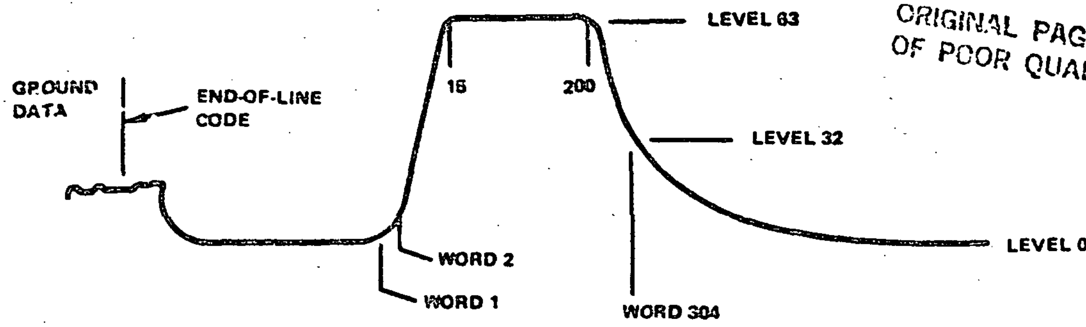

Figure 4. Typical Gray-Wedge Calibration Curve

4.3.2 MSS Internal Calibration curacy

For the maximum duty cycle period beginning 3 minutes after turnon (normal warmup time), the calibration wedge output provides the means to calibrate gain and offset values for Bands 1 through 4 (paragraph 4.1.1) within the following relative accuracies.

a. Channel to channel (within a band)

(1) Ratio of gains between channels: 2.0 percent peak to peak

(2) Offset differences between channels: ±15 millivolts (less than 0.24 quantum average)

b. Band to Band

(1) Ratio of band average gain (average of six channels) between bands: ±30 millivolts (less than 0.47 quantum level average)

c. Stability at any channel

(1) Gain change: ±2.0 percent over the maximum duty cycle

(2) Offset change: ± 12 millivolts over the maximum duty cycle period (less than 0.19 quantum level average)

The amplitude range of the calibration signal in the low-gain mode varies from a maximum of greater than 3.5 volts (level 55) to a minimum of less than 0.5 volt (level 8), and in the high-gain mode (Bands 1 and 2 only) from a maximum of greater than 4.0 volts (saturated level 63) to a minimum of less than 2.0 volts (level 32).

4.4 MSS SENSOR OUTPUT FORMAT

With the exception of the addition of a 4-bit spacecraft identification word, the MSS time-code format for Landsat-4 is identical to the 4-band format of Landsats-1, -2, and -3. The MSS data format for Landsat-4 is described in Appendix A.

4.5 MSS DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix B.

5. THEMATIC MAPPER SPECIFICATIONS

5.1 THEMATIC MAPPER RADIOMETRIC REQUIREMENTS

5.1.1 Radiometric Sensitivity

The TM output in each of Bands 1 through 5 and 7 have a SNR for specified input in accordance with Table 4. For a constant input radiance, the SNR is defined as the ratio of the output value (in units of radiance) averaged over at least 100 samples to the rms value of the noise equivalent radiance that is defined as the rms of the deviations of the output samples from the average value.

Table 4
Thematic Mapper Signal-to-Noise Ratios

Band	Constant in Band Input Radiance (mw/cm^2-sr)	Minimum SNR
1	0.28	32
2	0.24	35
3	0.13	26
4	0.19	32
5	0.08	13
7	0.046	5

The sensitivity of Band 6 is measured in terms of noise equivalent temperature difference (NETD). The NETD for Band 6 as measured after at least a 6-pixel settling time at 300 K is 0.5 K. The minimum scene temperature for this band is 260 K.

The signal drift of a detector channel with a constant radiance input shall not exceed one-fourth of the rms noise of the band from one scan to the next. The maximum allowable signal-level drift after 4 minutes or less of warmup (from orbital standby temperature) shall not exceed 2 percent of full scale per 24 hours (including 5 on-and-off cycles) and shall not exceed the rms noise level in any 30-second time period.

5.1.2 Radiometric Accuracy

Relative radiometric accuracy between bands operating in the reflective region shall be better than 2 percent. To maintain radiometric measurement accuracy for the total mission duration, an internal reference source is used to provide calibration data for ground correction. In addition, a dc restore technique is used on board to minimize the effects of low frequency noise and drift. A zero-radiance level is applied to the sensors when the shutters are closed to develop a zero-clamp level for the A/D circuitry. This zero-clamp level is fractionally updated before each sweep. The zero-clamp level appears as a sensor black-level output to the ground during the shutter-closed period.

NASA has no plans to acquire Sun calibration data for the TM.

5.1.3 Spectral Bands

The scanner operates in seven spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.45 to 0.52 micrometers
b. Band 2--0.52 to 0.60 micrometers
c. Band 3--0.63 to 0.69 micrometers
d. Band 4--0.76 to 0.90 micrometers
e. Band 5--1.55 to 1.75 micrometers
f. Band 6--10.40 to 12.50 micrometers
g. Band 7--2.08 to 2.35 micrometers

5.2 THEMATIC MAPPER GEOMETRIC CHARACTERISTICS

5.2.1 TM Geometry

The relationship between the Earth's surface and the data sampled by each TM detector is described in this section. The TM scan mirror is a 16- by 21-inch ellipse that provides a nearly linear scan motion covering a swath on the ground 185-km wide. A precision digital controller drives the mirror. A scan-line corrector, located behind the primary optics, compensates for the forward motion of the spacecraft and allows the scan mirror to produce usable data in both scan directions. Figure 5 shows the critical TM scanning components and the geometric relationship of the TM detectors to their ground-track projection.

Figures 6 and 7 give details of the detector geometry. The detector rows within a band are separated by 2.5 instantaneous fields of view (IFOV's). This is done because the multiplexer samples the even detectors 0.5 IFOV later than the odd detectors within a minor frame of data. In this way, the odd and even detectors are an integral multiple of IFOV's apart in space. The

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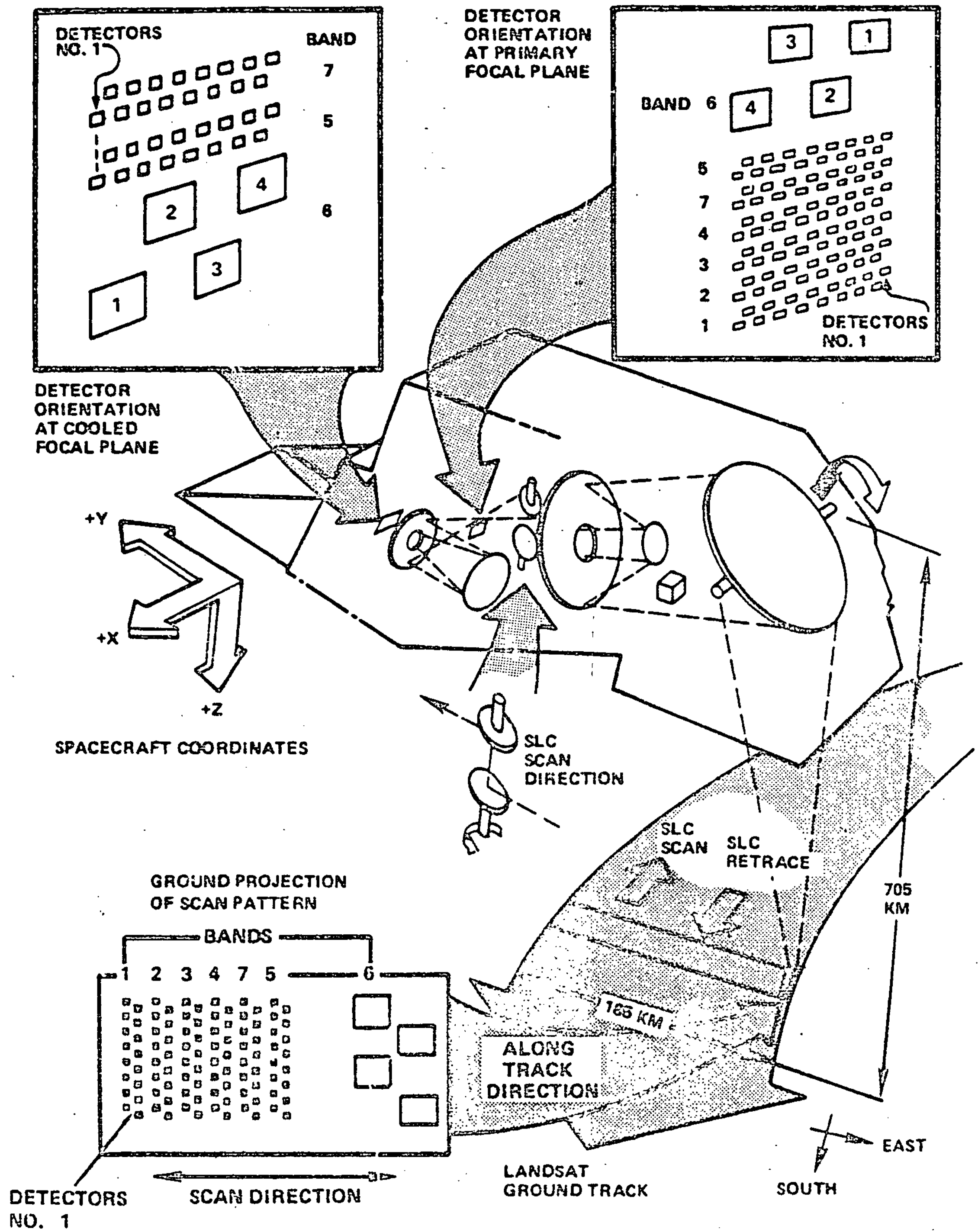

Figure 5. Detector Array Projections on Ground Track

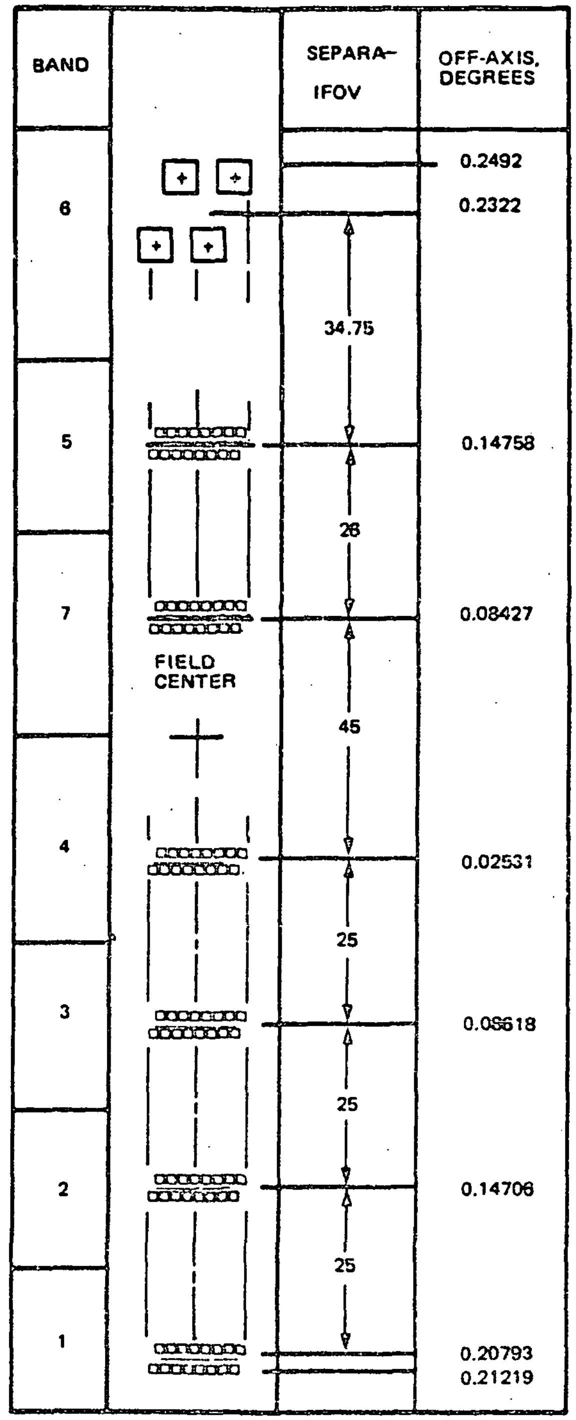

Figure 6. Detector Projection at Prime Focal Plane

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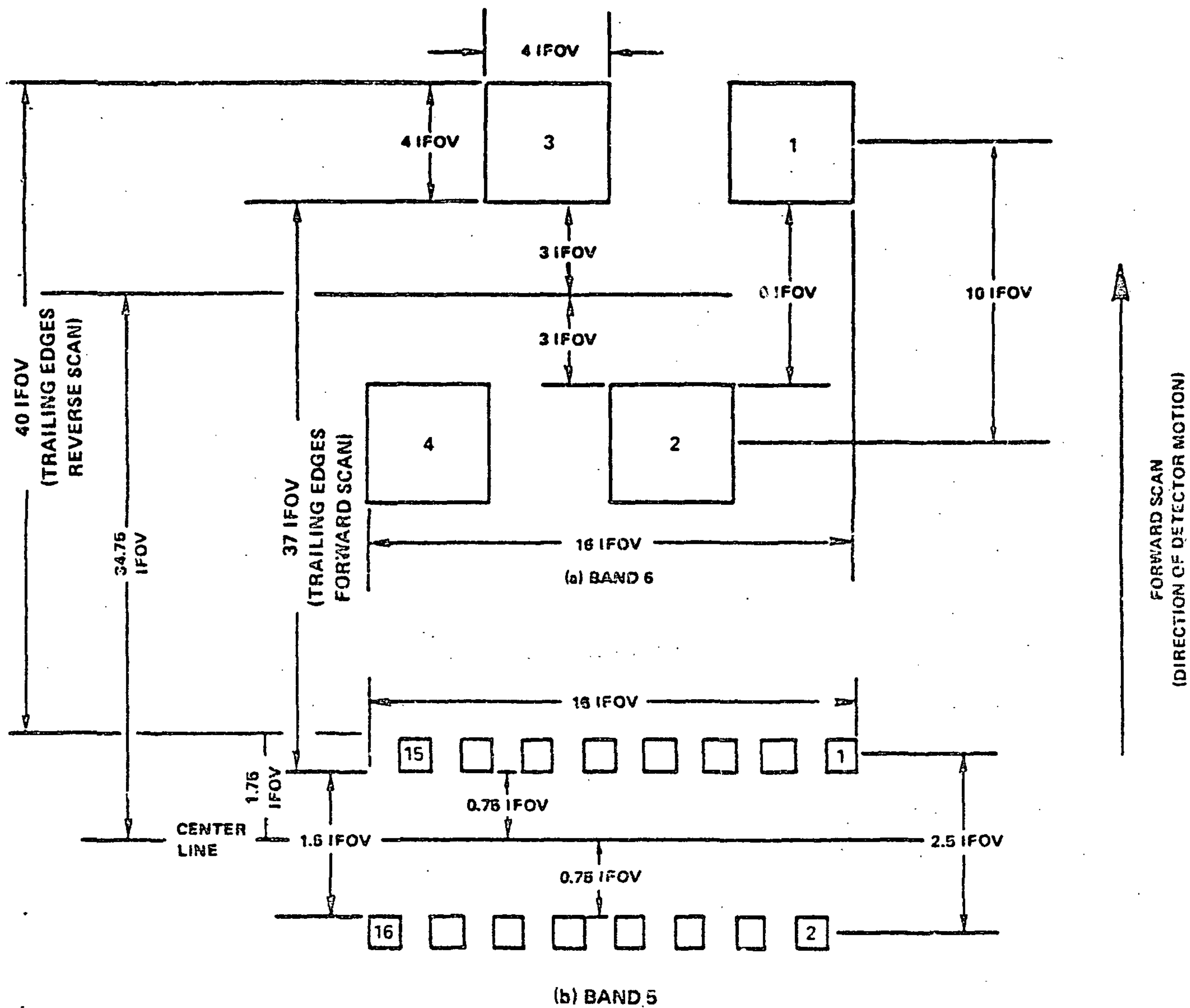

Figure 7. Details of Detector Spacing

spacing between Bands 5 and 6 is 34.75 IFOV's so that the edge of Band 5 detectors will line up with the edge of a Band 6 detector. Note that the Band 5 detector edge is 0.75 IFOV from the center line of the band, while the edge of the Band 6 detector is 3.0 IFOV's from the center line. Table 5 gives the minor frame adjustments between detectors. It includes nominal physical spacing and sample timing. Clarification of the Band 6 sampling scheme is provided in the following paragraphs.

Immediately after the line start code, the values of Band 6 Detectors 1 and 3 are held. The Band 6 Detector 1 sample is placed into the first minor frame after line start, and the sample of Band 6 Detector 3 is placed into the second minor frame. At the beginning of the third minor frame, the values of

Table 5
Detector Adjustment for Layout Geometry and Multiplexer Sampling

Scan Direction	Minor-Frame Adjustment	
	Reverse Scan (east to west)	Forward Scan (west to east)
Band 1 even	+3	-2
Band 1 odd	0	0
Band 2 even	-22	23
Band 2 odd	-25	25
Band 3 even	-47	48
Band 3 odd	-50	50
Band 4 even	-72	73
Band 4 odd	-75	75
Band 7 even	-117	118
Band 7 odd	-120	120
Band 5 even	-143	144
Band 5 odd	-146	146
Band 6 1	-186	183
Band 6 2	-174	175
Band 6 3	-185	184
Band 6 4	-173	176

Note: One Band 6 detector is sampled per minor frame. The sequence from line start is detector 1,3,2,4,1,3,2,4,1...

Band 6 Detectors 2 and 4 are held. The Band 6 Detector 2 sample is placed into the third minor frame, and the sample of Band 6 Detector 4 is placed into the fourth minor frame. The above process is then repeated starting with the fifth minor frame.

The odd detector values of Band 5 are held at the beginning of each minor frame as are Band 6 Detectors 1 and 3. The Band 5 odd detectors and Band 6 Detector 1 samples are placed into the minor frame at which they are held. Thus, as shown in Figure 7, there are nominally 37 minor frame samples between the trailing edges of Band 6 Detector 1 and odd Band 5 detectors on forward scans. Band 6 Detector 3 samples are placed in the minor frame after the Band 6 Detector 1 sample. Thus, there are 36 minor frame samples between odd detectors of Band 5 and Band 6 Detector 3 on forward scans.

For reverse scans, the values of Table 5 again represent the minor frame adjustment between the trailing edges of Band 6 Detectors and the other bands. As shown in Figure 7, there are 40 IFOV's between the trailing edge of Band 6 Detector 1 and Band 5 odd detectors.

The scan mirror assembly (SMA) operates in two modes: scan angle monitor (SAM) mode and bumper mode. The bumper mode is a third backup and will not be addressed in this document. The SAM mode can operate with scan mirror electronics number 1 (SME-1) or scan mirror electronics number 2 (SME-2). For each SME, there exists a fifth-order polynomial describing the nominal departure from linearity (or profile) of the scan mirror forward and reverse scans. (See Appendix C.) These nominal polynomial profiles must be adjusted on the basis of first half and second half scan time data due to observed profile wander (expected to be a slowly varying adjustment of ± 10 microradians at midscan over 2000 scans) and due to launch vibration profile shifts (expected to be less than ± 200 microradians at midscan).

Appendix E, TM Midscan Correction Summary, explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial.

The scan mirror electronics (SME) mode is indicated in Bits 6 and 7 of TM serial Word E. Serial Word E is given within the PCD TM housekeeping telemetry. See Section 5.4.7.2 (k).

The scan mirror produces nonlinear motions normal to its scan direction. This produces cross-scan or along-track errors that are defined using the polynomials given in Appendix C.

The scan line corrector (SLC) scans in the along-track direction and is intended to remove the along-track spacecraft and along-track Earth-rotation motion during the active scan time. The SLC position is reset by the end-scan pulse and initiates along-track scanning before the start-scan time. The SLC position at start-scan is a function of scan mirror turnaround time. The following are nominal SLC parameters:

Scan frequency (nominal)	13.99 Hz
Scan period (nominal)	71.462 ms
Scan rate in object space (nominal)	9.6 mr/sec

5.2.2 TM Geometric Accuracy

A line synchronization signal is generated once each scan line. The signals relate the position of the scanning system with respect to the TM frame.

Excluding the effects of possible spacecraft attitude changes, the path of any detector on the ground will not deviate from a straight line by more than 1.0 IFOV (maximum) during the active portion of each scan. The scan profile (angular position versus

time) can be described to within 0.1 IFOV (rms) by a smooth function of time with a maximum of three inflection points. A calibration profile has been derived from data taken during scan mirror subsystem tests and is provided in Appendix C.

The scan profiles in both along-track and cross-track directions are repeatable to the calibration profiles to within 0.1 IFOV (rms) over 400 scans and to within 0.2 IFOV (rms) over the operational lifetime of the instrument. To meet the scan profile repeatability requirements, scan profiles should be adjusted using first half scan time error and second half scan time error information that is provided in the high-data-rate stream.

The Flight Segment (FS) includes mechanical devices that are active during the time that images are being acquired. These mechanical devices cause low-amplitude motion that is passed through the spacecraft structure and results in attitude deviations of the TM optical axis. This motion is called jitter.

Anticipated rms TM jitter error, referenced to the spacecraft coordinate system, is as follows:

Frequency Range (Hz)	Error Magnitude (arc-sec, 1 sigma)
0--0.01	36.0 All axes
0.01--0.4	10.0 All axes
0.4--7	0.30 All axes
Greater than 7	0.93 Roll 0.20 Pitch 0.30 Yaw

Significant error is not expected to occur above 77 Hz.

Because of the developmental nature of the TM system, the NASA ground processing system is being designed to accommodate larger worst-case (peak) jitter errors of 20 arc-seconds above 7 Hz.

The amplitude and phase of jitter is expected to be asynchronous with respect to the TM scanning and thus requires measurement and correction during ground processing. The TM attitude measurement capability is up to nominally 2.0 Hz, using the attitude control inertial reference units (IRU's), and from nominally 2.0 to 125 Hz, using the angular displacement sensor (ADS). IRU and ADS outputs are combined on the ground to compute FS attitude deviations from nominal pointing. Below 125 Hz the TM is structurally rigid, and below 20 Hz the spacecraft center body is structurally rigid. ADS and IRU measurements fully characterize the attitude jitter of the TM optical axis.

5.2.3 TM Scan Rate

The scan rate (scene angular scan rate) during the usable portion of the scan will not deviate more than 1 percent (peak) from the average scan rate over any 30-second time period.

5.2.4 TM Overlap/Underlap

The peak overlap or underlap of IFOV's in adjacent scan lines of a band, not including the effect due to variations in range across the scan (i.e., bow-tie effect), altitude variation, or spacecraft jitter will be less than 0.2 IFOV error (in 395 of 400 measurements) over the full length of the scan lines when viewing the Earth.

5.2.5 TM Scan-Line Length

The length of a scan line is defined as the time required for scanning between the images of two sources that are at opposite ends of the scanned field of view. The TM line length (active) will vary by no more than ± 1 minor frame time from the line length averaged over 400 scans, exclusive of jitter effects external to the TM. Note that the specified performance (± 1 minor frame) is for the active scan line length. In operation,

the TM line length variation may be as large as ±20 minor frames when the TM and MSS operate simultaneously.

Major frame length (scan line start to the next scan line start) can vary up to an additional ±10 minor frames due to variation in mirror turnaround times.

5.3 TM INTERNAL CALIBRATION

The TM internal calibration system can operate in either automatic or backup mode. In the backup mode, command sequences are used to operate the three calibration lamps. An internal calibration lamp sequencer automatically sequences through the eight possible radiance levels available with the three lamps, using only one command. Calibration data will be present in approximately 50-image-pixel locations of each scan. The TM forward scan is defined as the mirror scan from west to east during daytime operation (i.e., with the spacecraft traveling north to south). Using this as a reference, the calibration data precede the dc restore on the reverse scan and follow the dc restore on the forward scan. Dc restore is a technique for minimizing the effects of low-frequency (L/F) noise and drift. A zero-radiance level is applied to the sensors when the shutters are closed to develop a zero-clamp level for the analog-to-digital circuitry. This zero-clamp level is fractionally updated before each sweep. The zero-clamp level appears as a sensor black-level output to the ground during the shutter-closed period. Calibration data begin approximately 7.8 milliseconds after the end-of-line (EOL) pulse for the forward scan and approximately 1.0 millisecond after the EOL pulse for the reverse scan. Each of the eight calibration steps will appear in 40 consecutive scans. Note that NASA does not use calibration lamp current to determine lamp state, and that there are no plans to put these items in the PCD.

Approximately 0.5 second is required for changing calibration levels because of the time required for the lamps to warm up to full radiance (or cool down in the case of the infrared bands). For this reason, the user should not plan to use the calibration data present in the first 7 scans of each 40-scan calibration level sequence. The user should examine a neighborhood of image-pixel values about the proper time and determine the location of the shoulder on the rising edge of the internal calibration curve. Look ahead 0.4 millisecond and search for the trailing edge of the shoulder of the calibration curve. Thirty contiguous pixels centered between the two shoulders can be averaged and used as valid calibration data. Almost anytime between 2.3 and 8 milliseconds can be used for the zero-radiance-calibration level when it occurs. The dc-restore flag is black, the same as no light for Bands 1 through 5 and 7. (Refer to Table 7 for the location of dc restore and blackbody data.)

	Command*	Lamps On	Percent of Full Scale
1	All lamps OFF/Lamp C OFF	None	0
2	Lamp A ON	A	40
3	Lamp B ON	A+B	70
4	Lamp A OFF	B	30
5	Lamp C ON	B+C	50
6	Lamp A ON	A+B+C	90
7	Lamp B OFF	A+C	60
8	Lamp A OFF	C	20

The TM calibration lamp sequence is synchronous with the scans. Theoretically, it is possible to determine which of the eight calibration levels is in effect for a particular scan line. The calibration level (which lamps are on and stable) at any particular time must be derived from the data. These calibration levels

*There are 40 scans between each command.

are not anticipated to be exact, but no tolerances are specified. There are also no specification limits on calibration pulse rise and fall time. Actual digital values depend primarily on the internal calibration (IC) lamp configuration and the band number. Representative values can be deduced from Figures 7a and 7b. The brightest level (111), with all three IC lamps on, causes saturation at digital count 255 in Band 4.

Given the preceding calibration data sequence, the user can develop the technique to locate and extract calibration data. A temperature-controlled blackbody and a temperature-measured shutter surface provide the calibration reference points for the four Band 6 Detectors. Band 6 detectors view the temperature-measured shutter surface during the dc-restore calibration period and the temperature-controlled blackbody during the calibration period of each mirror scan. Refer to Table 7 for the location of these two periods in the TM forward and reverse scans. The calibration shutter and blackbody temperatures are measured and inserted in mission telemetry (minor-frame words 49 and 47, respectively - see Table 13), and in the payload correction data (PCD) TM housekeeping telemetry (reference 5.4.7.2.k). Absolute calibration will be necessary for the thermal IR channel to account for the blackbody shading factor. Compensation for temperature drift and possible emissivity variations is expected to be required throughout the mission.

5.4 TM OUTPUT FORMAT

The TM output is an 84.903 $\pm$0.080 Mbps nonreturn-to-zero mark (NRZ-M) serial bit stream. This signal employs differential transmission and has redundant outputs. Eight TM bits are grouped to form a word; words are grouped into minor frames; and minor frames are used to form major frames. Each major frame contains all data applicable to the one sweep (71.46 milliseconds) of the scan mirror. The output format is shown in

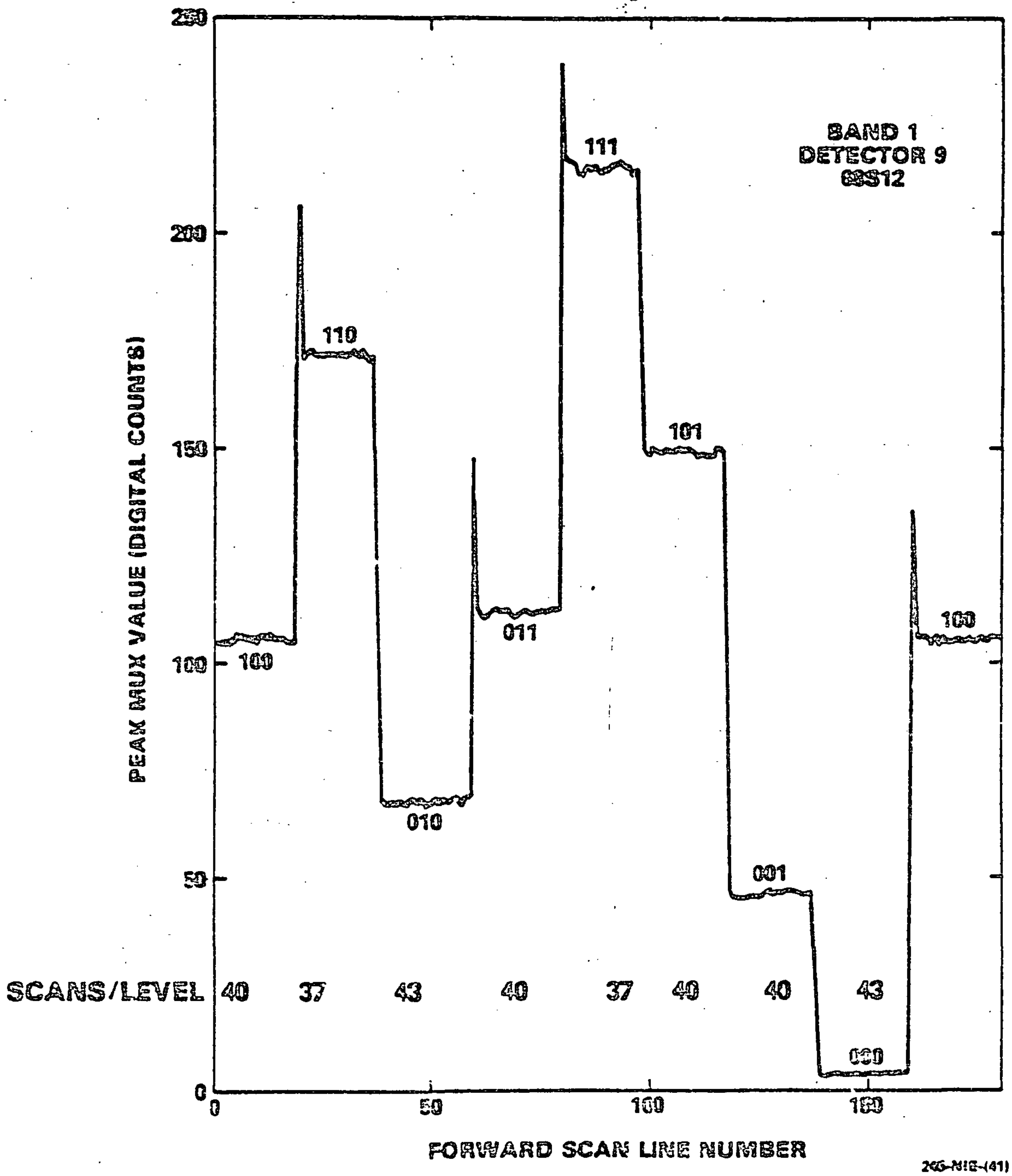

Figure 7a. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Turnon Overshoot

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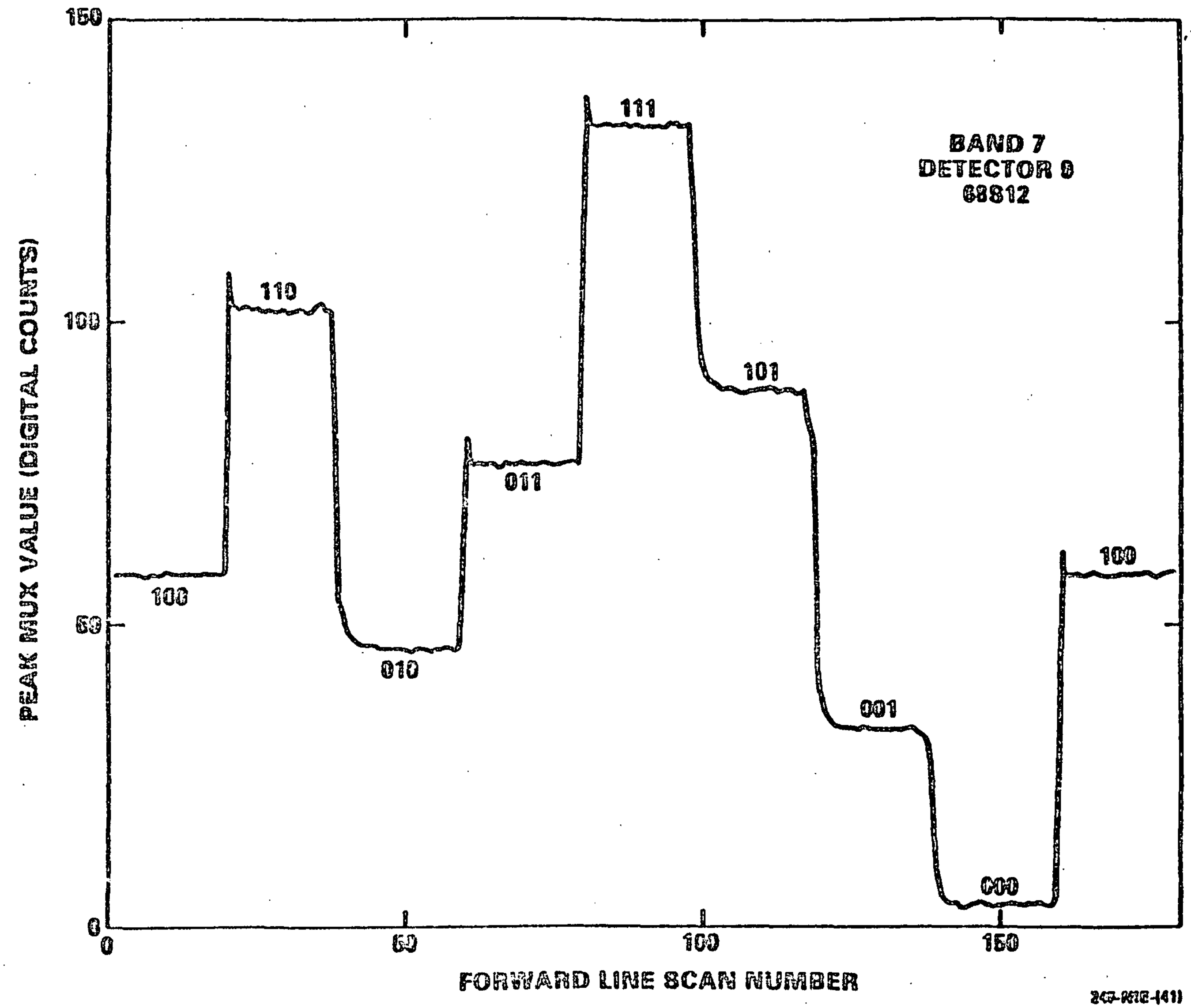

Figure 7b. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Overshoot and Thermal Relaxation

Figure 8 and is described in the following subparagraphs. The key parameters are as follows:

Swath angle: 15.390 degrees (nominal)
Scan rate: 4.42191 rad/sec (nominal object space)
Dwell time: 9.611 μsec
Line length: 6320 IFOV's (nominal)
Filter frequency: 52.02 kHz
Data rate: 84.903 $\pm$0.080 Mbps
IFOV Bands 1 through 5 and 7 (nominal values) = 42.5 μrad; Band 6 = 170.0 μrad
Scan period: 142.922 msec (nominal)
Scan frequency: 6.9968 Hz (nominal)
Active scan time: 60,743 microseconds (nominal)
Turnaround time: 10.719 msec (nominal)

Figure 9 details the pseudorandom noise code for the TM scan-line start.

All words in the format, except for minor-frame sync, scan-line start, and "not-pseudonoise" ($\overline{PN}$), will have the last four bits inverted and will then be PN-encoded.

5.4.1 Major-Frame Sync

The major-frame sync is referred to herein as the scan-line start (SLS). The SLS begins with the third word after the word in which the SLS pulse from the scanner has been sensed. The SLS consists of 816 bits of PN code generated from a 10-bit register so that the last 10 bits of the SLS are 10 logical ones. (See paragraph 5.4.5, PN Encoding.) The actual bit pattern is shown in Figure 9. The SLS preempts all data; however, word sync is maintained from scan to scan. The SLS words are not PN-encoded.

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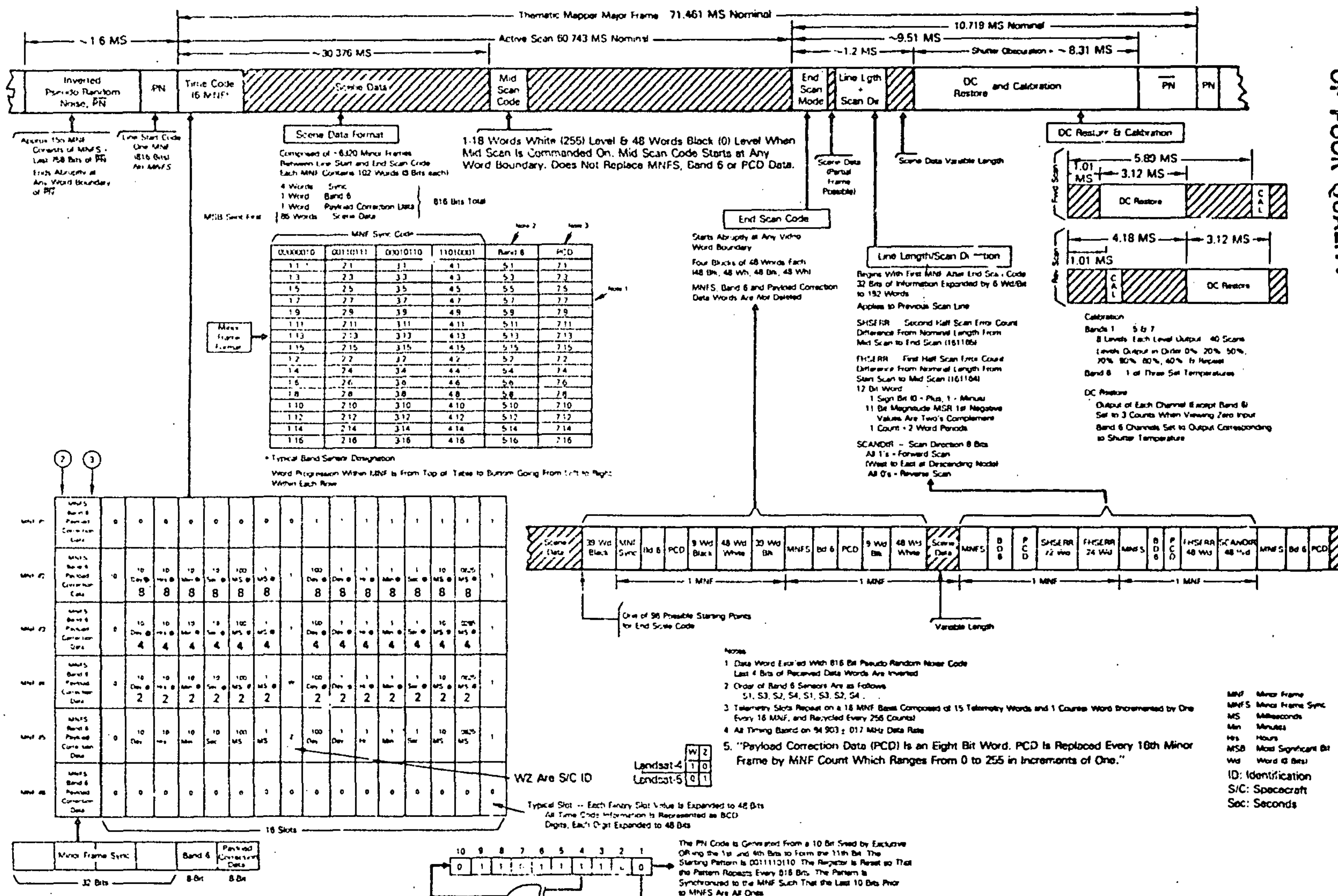

Figure 8. Thematic Mapper Data Format

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```
  1   00111101101101000000010100000101101010100011110111
 51   10010010110000001001100100010100011011011100000111
101   10001110111111100100001100010110111010000110101011
151   00111100101110110010000010001001001100000101100010
201   10011101100111000101111110101000101110110101100001
251   10011011010100000111010011110100110101001001110000
301   01111100111001101111010001010101101111100001001110
351   10001110101111101101001000010000101001010110001110
401   01111110110000100011010011100100111100001101111011
451   000110001 1101111101001001010000001101000110010111
501   01001011101000100010110011010010100100011000011101
551   01111000001011100101011100111011101110011001110101
601   01110111101100101000100110110001000001110010111100
651   10100110011001010101001111110011000110101111001101
701   01101001100010010111100001011110101010111111111010
751   00001010100101111000101011110111010100110111001000
801   1110001111111111
```

Figure 9. Pseudonoise Code for Thematic Mapper Scan-Line Start, Data Encoding and Complement of the Epilog

5.4.2 Major-Frame Format

Since each TM word major frame contains the data relative to a single mirror sweep, the frame is of variable length. The major-frame length during normal operations will be 7435.3 ± 30 minor frames. Major frames are partitioned into minor frames. The major-frame formats are defined in Tables 6 and 7. (See Table 8 for the time-code format and Figure 8 for the TM data format.)

5.4.3 Minor-Frame Format

Each scan is divided into minor frames of 102 words of 8 bits each. The format for a single minor frame is shown in Figure 10. All minor frames except the last one are composed of 816 bits. The last minor frame of any major frame may contain any integral number of 8-bit words up to the full 102.

5.4.4 Minor-Frame Sync

The minor-frame sync is a 32-consecutive-bit sync word. The first bit of the first minor-frame sync occurs immediately following the 816-bit SLS and is repeated every 816 bits until the next SLS reinitializes the sequence. The sync word is not PN-encoded and has been selected to maximize the opportunity to correct for bit slippages. The sync word can be interrupted by the SLS at the 8-bit word boundaries. The selected bit pattern for the sync word can be represented as the hexadecimal number 02 37 16 D1.

5.4.5 PN Encoding

All TM data except for: (1) major-frame sync, (2) minor-frame sync, and (3) postamble data are PN-encoded. Encoding is accomplished by inverting the 4 least significant bits (LSB's) of each 8-bit word and exclusive ORing the resultant word with a pseudo-random noise (PN) code. The PN code (Figure 9) is generated from

Table 6
Thematic Mapper Major-Frame Format

Nominal Number of Minor Frames Required	Starting Minor Frame	Data Type
1	0	Major-frame sync code
6	1	Time code
3159 ±10	7	Scene
2	**	Midscan code*
3159 ±10	3161 ±10	Scene
3 +0, -1	6320 ±20	End-scan code--START
	End scan +2	End-scan code--END
3	End scan +3	Line length
155 ±30	End scan +960	Postamble--START
	7435.3 ±30	Postamble--END

*If command ON, otherwise replaced with scene data.
**Approximately at center of scan.

Table 7
Thematic Mapper Data Format
(From scan line start to end of turn-around period)

	Forward Scan West to East at Descending Node		Reverse Scan East to West at Descending Node	
Event	Start Minor Frame Count	End Minor Frame Count	Start Minor Frame Count	End Minor Frame Count
End Scan	6320 ±20	End scan +2	6320 ±20	End scan +2
Line Length and Scan Direction	End scan +3	End scan +4	End scan +3	End scan +4
Shutter Obscuration	6445 ±50	7310 ±50	6445 ±50	7310 ±50
DC Restore	End scan +230	End scan +555	End scan +560	End scan +885
Calibration	7028 ±50	7148 ±50	6520 ±50	6640 ±50
$\overline{\text{PN}}$	End scan +960	7435.3 ±30	End scan +960	7435.3 ±30

Note: The start and end times are nominal times.

Table 8
Thematic Mapper Time-Code Format

	A	B	C	D	E	F
1	0	0	0	0	0	0
2	0	10 D(8)	10 D(4)	10 D(2)	10 D(1)	0
3	0	10 H(8)	10 H(4)	10 H(2)	10 H(1)	0
4	0	10 M(8)	10 M(4)	10 M(2)	10 M(1)	0
5	0	10 s(8)	10 s(4)	10 s(2)	10 s(1)	0
6	0	100 ms(8)	100 ms(4)	100 ms(2)	100 ms(1)	0
7	0	1 ms(8)	1 ms(4)	1 ms(4)	1 ms(1)	0
8	0	X1	X2	X3	X4	0
9	1	100 D(8)	100 D(4)	100 D(2)	100 D(1)	0
10	1	1 D(8)	1 D(4)	1 D(2)	1 D(1)	0
11	1	1 H(8)	1 H(4)	1 H(2)	1 H(1)	0
12	1	1 M(8)	1 M(4)	1 M(2)	1 M(1)	0
13	1	1 s(8)	1 s(4)	1 s(2)	1 s(1)	0
14	1	10 ms(8)	10 ms(4)	10 ms(2)	10 ms(1)	0
15	1	1/2 ms	1/4 ms	1/8 ms	1/16 ms	0
16	1	*	*	*	*	0
Output Sequence: A1-A16, B1-B16, C1-C16, D1-D16, E1-E16, F1-F16						

D - Day
H - Hours
M - Minutes
s - Seconds
ms - Milliseconds

* = Spares (set to "1")
() = BCD weight
X(1-4) = spacecraft ID as follows:
1000 = Landsat-4
1101 = Landsat-4'

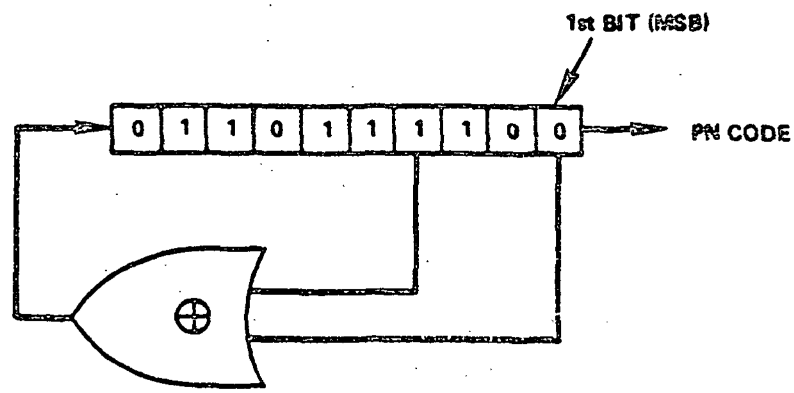
a 10-bit seed word (0011 1101 10) by exclusive ORing the 1st and 4th bits to create the 11th bit, as shown below. The resultant 1024-bit repeating code is truncated (reset to the seed word) each minor frame so that the last 10 bits of the code used in each minor frame are "1's." Note that, since the first 4 words (32 bits) of each minor frame are minor-frame sync and not encoded, the first bit used in encoding is the 33rd bit of the sequence produced by the generator shown. The generator also produces the PN code used for major-frame sync and the inverted PN code used as postamble.

The PN code generator is reset to a fixed value (00 1111 0110) for the start of scan line and for the start of each minor frame

SYNC	SYNC	SYNC	SYNC	BAND 6	PCD
B1 S1	B2 S1	B3 S1	B4 S1	B5 S1	B7 S1
B1 S3	B2 S3	B3 S3	B4 S3	B5 S3	B7 S3
B1 S5	B2 S5	B3 S5	B4 S5	B5 S5	B7 S5
B1 S7	B2 S7	B3 S7	B4 S7	B5 S7	B7 S7
B1 S9	B2 S9	B3 S9	B4 S9	B5 S9	B7 S9
B1 S11	B2 S11	B3 S11	B4 S11	B5 S11	B7 S11
B1 S13	B2 S13	B3 S13	B4 S13	B5 S13	B7 S13
B1 S15	B2 S15	B3 S15	B4 S15	B5 S15	B7 S15
B1 S2	B2 S2	B3 S2	B4 S2	B5 S2	B7 S2
B1 S4	B2 S4	B3 S4	B4 S4	B5 S4	B7 S4
B1 S6	B2 S6	B3 S6	B4 S6	B5 S6	B7 S6
B1 S8	B2 S8	B3 S8	B4 S8	B5 S8	B7 S8
B1 S10	B2 S10	B3 S10	B4 S10	B5 S10	B7 S10
B1 S12	B2 S12	B3 S12	B4 S12	B5 S12	B7 S12
B1 S14	B2 S14	B3 S14	B4 S14	B5 S14	B7 S14
B1 S16	B2 S16	B3 S16	B4 S16	B5 S16	B7 S16

B = BAND NUMBER S = SENSOR NUMBER

Figure 10. TM Minor-Frame Format



thereafter. This starting code, along with all other codes produced by the PN code generator, are shown in Figure 9. Note that the first 32 bits of each minor frame are not PN-encoded. (See Figure 10.) PN encoding is performed only on bits 33 through 816 of each minor frame. The PN code bits (Figure 9) are exclusive ORed with corresponding video data word bits (the last 4 bits of each video word are inverted before the exclusive OR process is performed). The PN-encoded data are transmitted to ground, most significant bit (MSB) first. The PN inverse code consists of 4 words of minor-frame sync, Band 6 sensor word, and PCD word followed by 768 bits of inverted PN code (PN bits 49 to 816 inverted) repeated continuously for approximately 1 millisecond Refer to Table 8 for the timing of PN encoding.

5.4.6 Band 6 Sensor Word

The outputs of the 4 thermal-band detectors of Band 6 appear in sequential minor frames as the first 8 bits immediately following the minor-frame sync. The signal from Detector 1 of Band 6 occurs in the first minor frame after SLS and every fourth minor frame thereafter. The output sequence is Detector 1, Detector 3, Detector 2, then Detector 4. Band 6 sensor words are PN-encoded.

5.4.7 Payload Correction Data

The PCD contain all data required by ground stations for correcting TM sensor data. The data sources, data, and timing

associated with their collection, formatting, and transmission to ground stations are provided in this section for the TM payload data stream. The PCD are transmitted to ground stations by a 32-kbps digital signal modulated on the S-band carrier and within the TM payload data stream, carrying the following types of data:

- Angular Displacement Sensor (from the Angular Displacement Sensor Assembly-ADSA)
- ADS Temperature (from ADSA)
- Gyro Data (from OBC)
- Gyro Drift Data (from OBC)
- Attitude Estimate (from OBC)
- Ephemeris (from OBC)
- TM Housekeeping Data (from OBC)
- Spare Housekeeping Data (from OBC)
- Spacecraft Time Code (from the Power Distribution Unit-P
- MUX Status (generated in the PCD formatter)
- A/D Ground Reference (from ADSA)
- Sync (generated in the PCD formatter)
- Major Frame Identification - MFID (generated in the PCD formatter)
- Telemetry Frame Correlation (generated in the PCD formatter)

The PCD contain information from many sources, including a 2- to 125-Hz bandwidth jitter measuring sensor. The jitter information is derived from a three-axis angular displacement sensor (ADS) that is mounted on the TM instrument. Calibration of this sensor is based on prelaunch test results. The ADS output will be quantized to 12 bits per axis. The PCD are formatted, subsequently multiplexed onto a 32-kbps digital S-band data link, and inserted in the TM payload data stream.

The sixth word in each TM minor frame contains either 8 bits of PCD or, in every 16th minor frame, a minor-frame counter number.

The minor-frame count commences with a count of "zero" at minor-frame 16 (the 16th minor frame of video after SLS) and is incremented by one and inserted every 16 minor frames thereafter. This counter also resets to "0" beginning in the 16th minor frame after end-of-line (and after midscan, if in use). The PCD "word" is either SYNC, FILLER, or DATA. (See Paragraph 5.4.7.1.) The words are output in the order FILLER, SYNC, DATA, DATA, DATA, FILLER, FILLER, FILLER.... SYNC words are hexidecimal 16's (00010110) and FILLER words are hexidecimal 32's (00110010). DATA words are repeated twice (three words total) and represent eight unique bits of PCD. Approximately 22 filler words are required between each data set. PCD and minor-frame counter words are PN-encoded, and the left-most bit of MSB is output first. PCD word sync will be repeated in the unpacked PCD format every 26 ± 1 words.

5.4.7.1 Packed and Unpacked PCD Formats--The PCD, which are asynchronous with TM data, are generated at 4 kbytes/sec. The TM requests a PCD word every minor frame or at a rate of 97,545 Hz. As a result, the PCD transmitted in word 6 of the wideband TM payload data stream are in an unpacked format. Filler words are used to rate buffer the PCD 4 kbytes/sec generation rate up to the 97,545 Hz TM PCD word request rate. The number of filler words required to accomplish this rate buffering will vary. The user will be required to synchronize on the unpacked format data stream, extract the data words, perform a majority vote on the validity of the three identical data words to select one of the three words, and pack the selected data words into a buffer. The unpacked PCD format (TM minor-frame word 6) must be reformatted to match the packed PCD format by the user before the data can be extracted. The processing necessary to transform the PCD data in word 6 of the TM minor frames to the packed PCD format is shown in Figure 11.

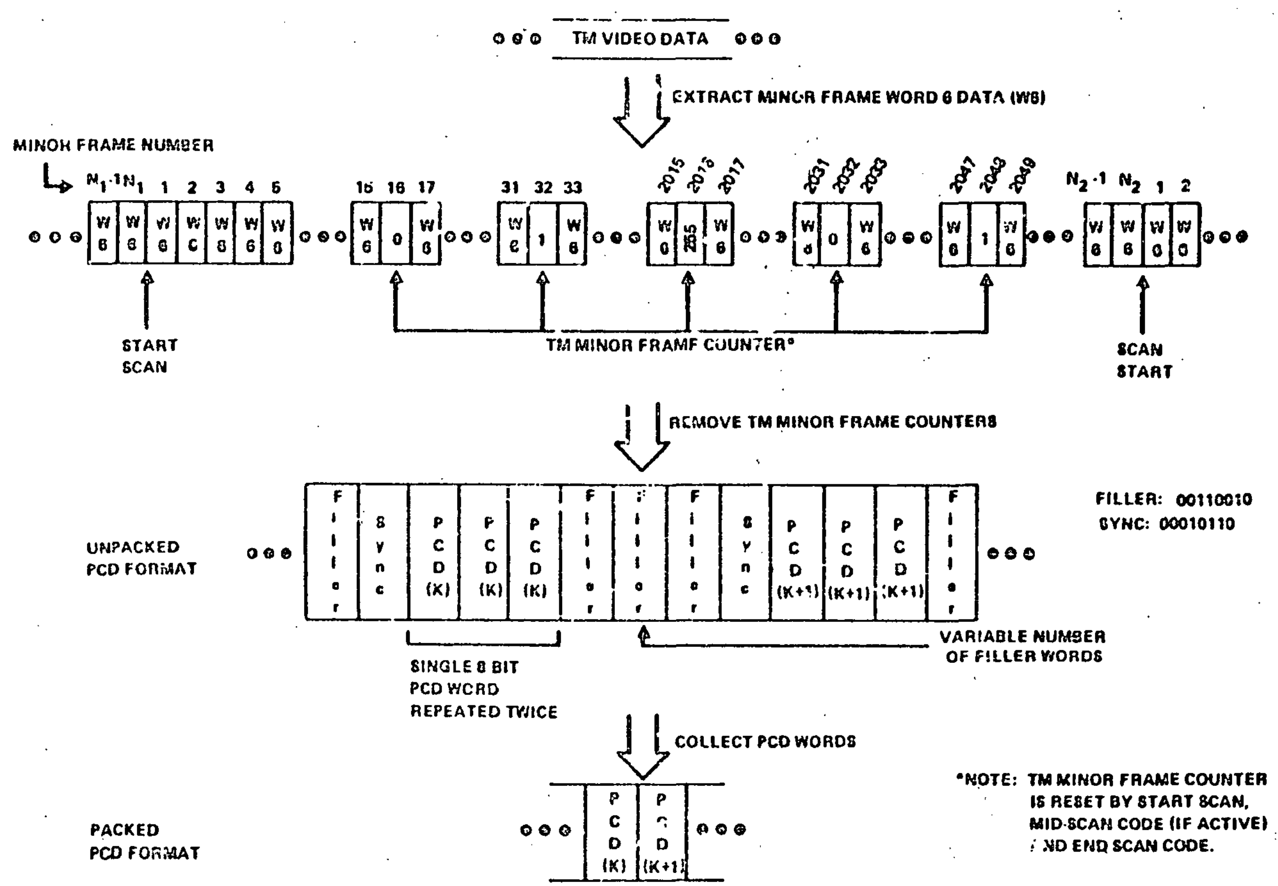


Figure 11. PCD Extraction from TM Video Data

a. Unpacked PCD format (TM minor-frame word 6)

TM Payload Word 6 (PCD word content)		Value
FILLER		HEX 32 (00110010)
SYNC		HEX 16 (00010110)
DATA	one 8-bit data value	
DATA	repeated twice	
DATA		
FILLER		HEX 32
FILLER		HEX 32
FILLER		HEX 32
•		
•		
•		

It should be noted that PCD are replaced in minor frames 16, 32, 48 ... by minor-frame ID words.

b. Packed PCD format (by user)

Cycle length: 4 major frames
Subcom sequence length: 4 major frames
Major-frame length: 128 minor frames
Minor-frame length: 128 words, 8 bits/word (Figure 12)

(1) PCD cycle format (Figure 12)

(2) PCD major-frame format (Figures 13 and 14)
Sync word hexidecimal FAF320

(3) PCD subcom (Figures 15, 16, and 17)

5.4.7.2 Data and Timing--The timing of all PCD data items is given, referenced to the PCD time code for the PCD cycle in which the data item appears. The PCD time code is described under Section g. of this paragraph.

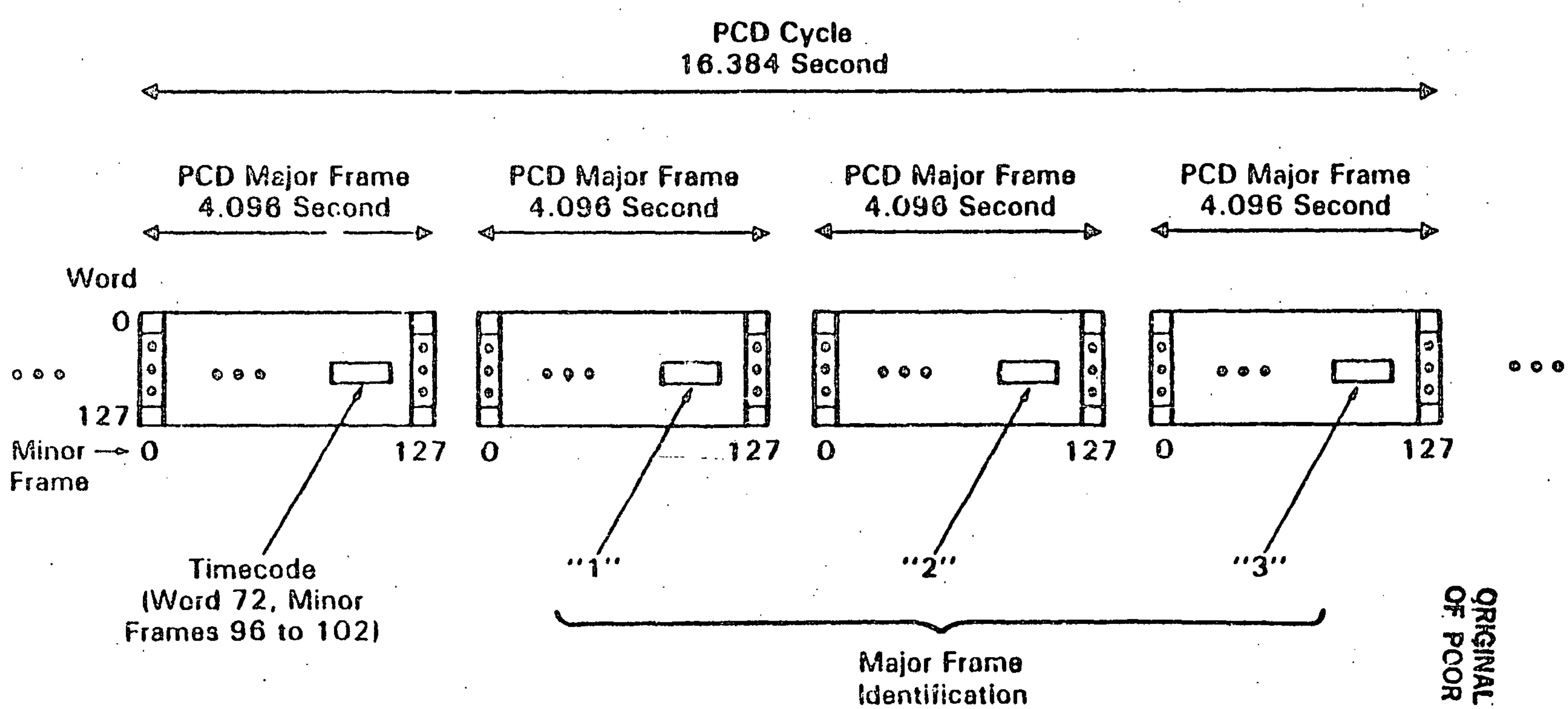


Figure 12. Payload Correction Data - Cycle Format

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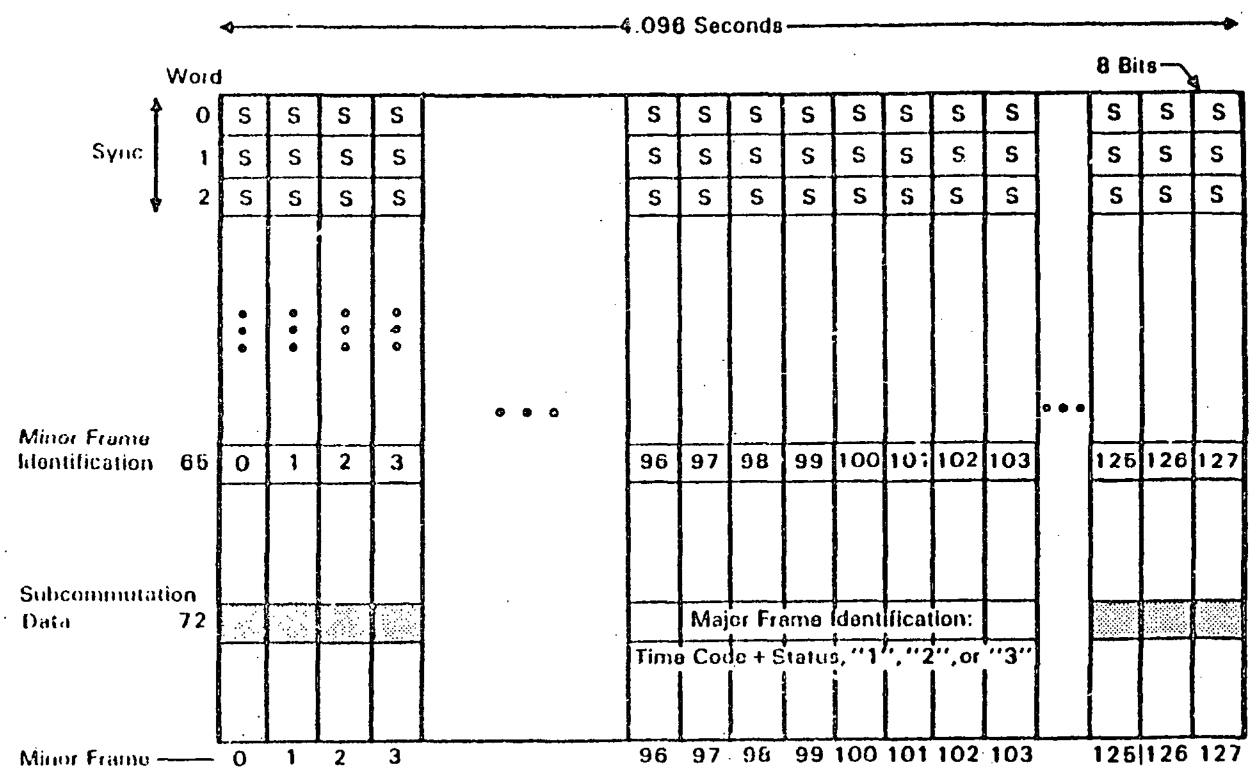

Figure 13. Payload Correction Data - Major Frame Format

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32 msec (120 WORDS)

SYNC		0,1,2
ADS	1*	3,4
ADS	2	5,6
ADS	3	7,8
		9
		10
ADS	1	11,12
ADS	2	13,14
ADS	3	15,16
GYRO (FIG 15)		17
		18
ADS	1	19,20
ADS	2	21,22
ADS	3	23,24
		25,26
ADS	1	27,28
ADS	2	29,30
ADS	3	31,32
GYRO (FIG 15)		33
		34
ADS	1	35,36
ADS	2	37,38
ADS	3	39,40
		41,42
ADS	1	43,44
ADS	2	45,46
ADS	3	47,48
GYRO (FIG 15)		49
		50
ADS	1	51,52
ADS	2	53,54
ADS	3	55,56
		57,58
ADS	1	59,60
ADS	2	61,62
ADS	3	63,64

WORDS IN MINOR FRAME

MFID		65
ADS	1	66,67
ADS	2	68,69
ADS	3	70,71
SUB COMM (FIG 13)		72
		73
ADS	1	74,75
ADS	2	76,77
ADS	3	78,79
		80
GYRO (FIG 15)		81
ADS	1	82,83
ADS	2	84,85
ADS	3	86,87
		88,89
ADS	1	90,91
ADS	2	92,93
ADS	3	94,95
		96
GYRO (FIG 15)		97
ADS	1	98,99
ADS	2	100,101
ADS	3	102,103
		104,105
ADS	1	106,107
ADS	2	108,109
ADS	3	110,111
		112
GYRO (FIG 15)		113
ADS	1	114,115
ADS	2	116,117
ADS	3	118,119
		120,121
ADS	1	122,123
ADS	2	124,125
ADS	3	126,127

WORDS IN MINOR FRAME

* 1 = roll (x), 2 = pitch (y) and 3 = yaw (z)

Figure 14. PCD Minor-Frame Format

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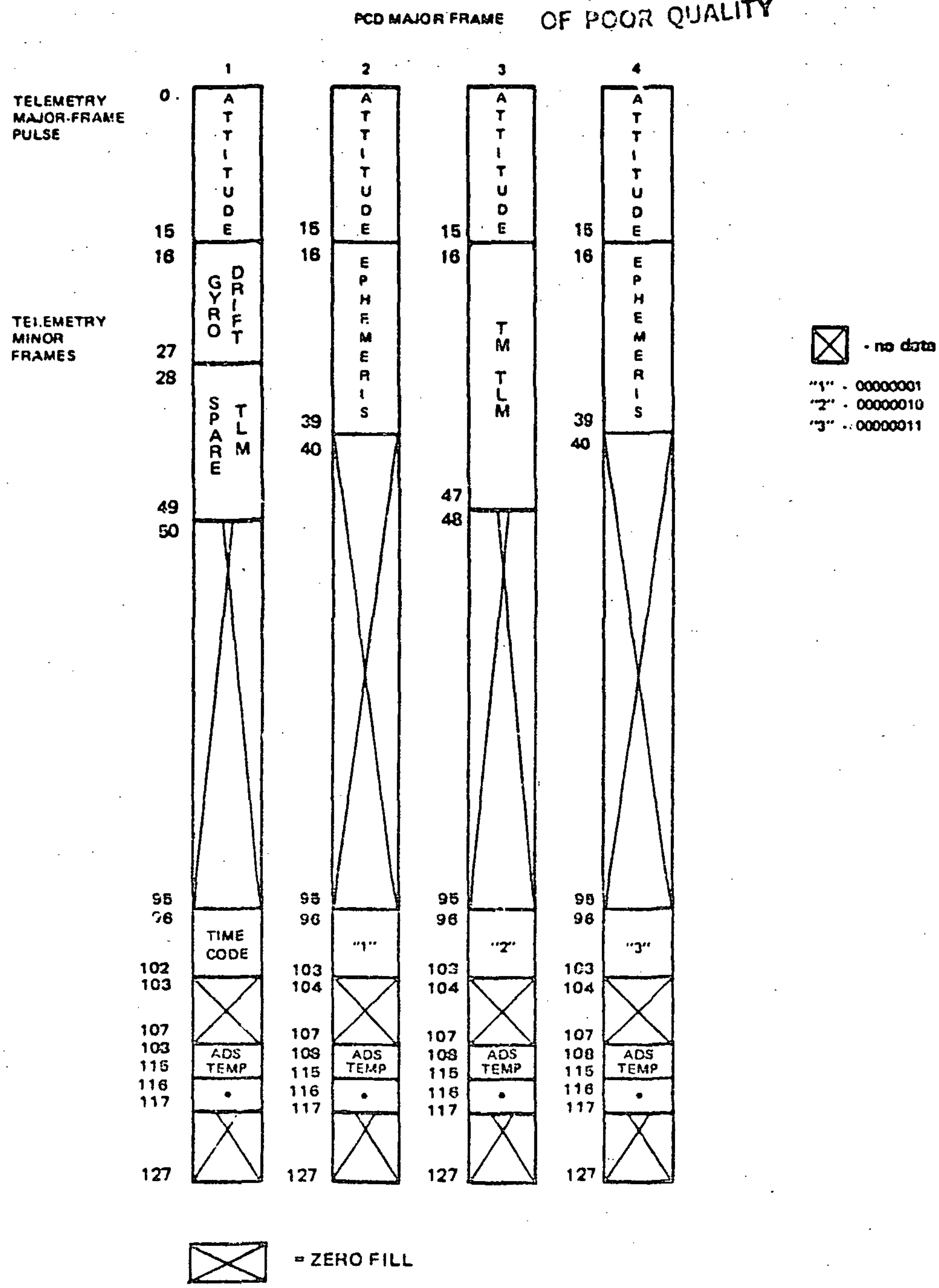

*Frame Error and A/D Ground Ref. (See Figure 16).

Figure 15. Subcommutation Data (Word 72)

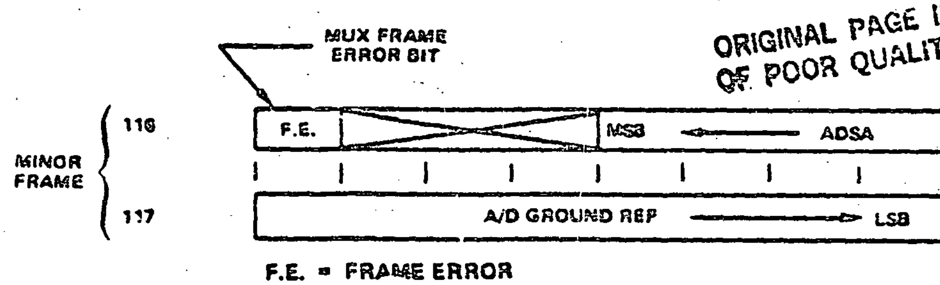

Figure 16. Frame Error and A/D Ground Reference

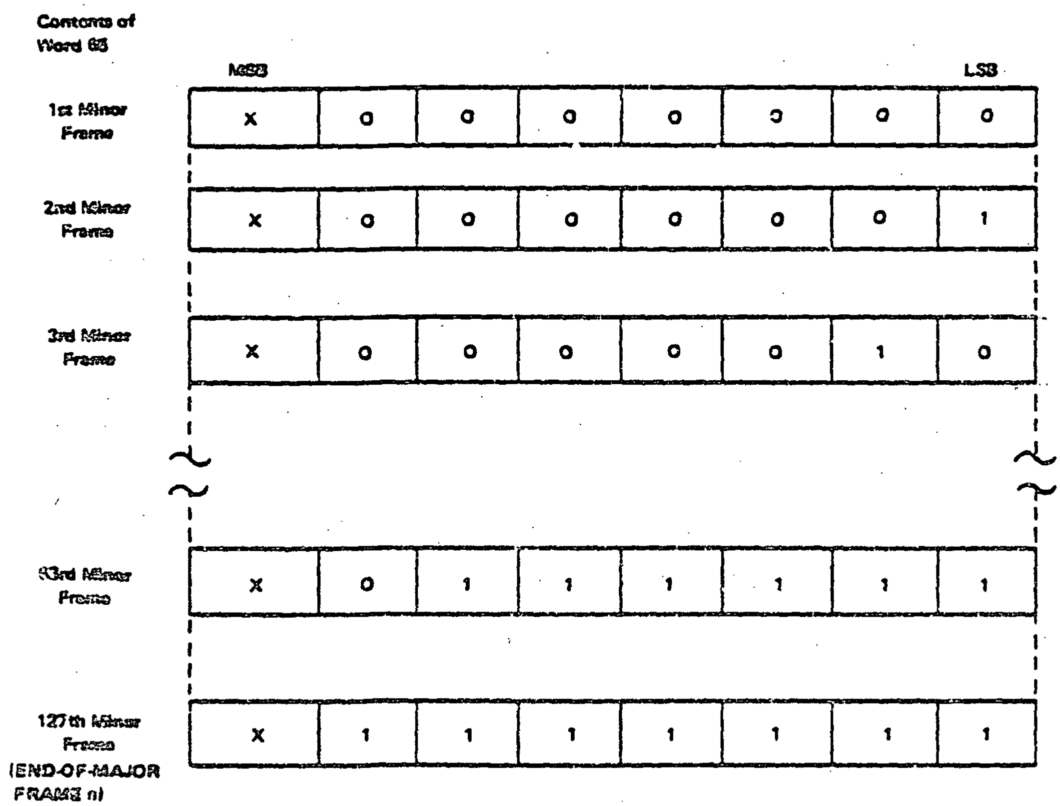

Figure 17. Frame-Counter Identification Bit Pattern

a. ADSA--The Attitude Displacement Sensor Assembly (ADSA) consists of three nominally orthogonal ADS sensors. The ADSA is mounted on the TM telescope. Each axis of the ADSA will be sampled every 2 milliseconds. The sample will be converted to a 12-bit integer word and inserted in two consecutive words of the format, with the four MSB's of the first word set to zero.

Digital count 0 is maximum positive angular displacement, and digital count 4095 is maximum negative angular displacement. The LSB of each count is $250/2^{11}$ microradians.

Each ADSA axis is sampled every 0.002 second. There are 8192 samples of each ADSA axis in a PCD cycle. The sample timing is given below.

> Let the samples of any one axis appearing in a PCD cycle be numbered N = 0,1,2,...,8191. Then the time for each sample is defined relative to the PCD time code of the PCD cycle by:

ADSA AXIS	SAMPLE TIMES
1	PCD Time Code + (2N + 3/8) milliseconds
2	PCD Time Code + (2N + 7/8) milliseconds
3	PCD Time Code + (2N + 1 + 3/8) milliseconds

Each axis of the ADSA has a nominal 2.0 to 125.0 Hz bandwidth. The exact transfer function to rotational motion is given in Appendix C.

The nominal relative alignment between the ADS and the spacecraft is $X_{ADS} = X_{S/C}$ where Y_{ADS} and Z_{ADS} are rotated CCW nominally 20° about $X_{S/C}$. Appendix F defines the exact alignment.

No attempt to calibrate the ADSA postlaunch is planned. Predicted jitter levels indicate the need for all ADS data. If this analysis proves to be too conservative, less use of ADSA data may be possible in routine processing. NASA has designed its processing to use all ADSA data.

b. ADSA Temperature--Up to four ADSA-related temperatures will be sampled once a PCD major frame (4.096 sec). Each sample will be converted into 2 8-bit words with the first 4 bits of the first word set to zero. As before, the data will be sampled in the word time preceding the first data word. That is:

	Minor Frame	Data Word	Sample Time (word)
Temperature 1	108-109	72	71 (108)
Temperature 2	110-111	72	71 (110)
Temperature 3	112-113	72	71 (112)
Temperature 4	114-115	72	71 (114)

ADSA temperature is in degrees centigrade with an LSB weight of 0.1758°C.

Temperature compensation of ADSA and DRIRU data does not appear to be necessary and is not planned at this time.

c. Gyro Data--Each axis of both dry rotor inertial reference units (DRIRU's) is sampled by the OBC every 64 milli seconds. The data will consist of a 24-bit word for each axis (a total of 72 bits). Figure 18 shows the format of the gyro data in the PCD. Each sample consists of three 8-bit bytes. The three bytes must be assembled into the 24-bit word. The data are in 2's complement format with the most significant bit first.

About each axis, the DRIRU generates a signed pulse for each 0.05 arc-sec of angular motion. A positive pulse increments a 24-bit register and a negative pulse decrements the register. A positive pulse is generated by a negative rotation about the gyro axis. The OBC samples this register every 64 milliseconds.

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Minor Frame	Word in Minor Frame											
		17		33		49		81		97		113
0		⊠		⊠		⊠		1_1		1_2		2_1
1		1_3		2_2		2_3		3_1		3_2		3_3
2		⊠		⊠		⊠		1_1		1_2		2_1
3		1_3		2_2		2_3		3_1		3_2		3_3
⋮		⋮		⋮		⋮		⋮		⋮		⋮

⊠ = No Data

1_n = X axis (roll) byte n
2_n = Y axis (pitch) byte n
3_n = Z axis (yaw) byte n

Three eight-bit-bytes (n = 1 - 3) are required per axis. The MSB is output first.

Figure 18. Gyro Data

Pitch orbital motion and gyro drift cause the register to periodically overflow. The register is reset to zero when its value is positive $2^{23}-1$ and a positive pulse is received or when its value is negative $2^{23}-1$ and a negative pulse is received.

Each DRIRU axis has a nominal 0-2 Hz bandwidth. The exact transfer function is given in Appendix C.

There are 256 samples of each DRIRU axis during a PCD cycle. Each axis is sampled at the same time. The sample timing is as follows:

> Let the gyro samples for any one axis appearing in a PCD cycle be numbered N = 0,1,...,255. Then the time for each sample is the PCD time code plus (64N - 28) milliseconds.

During ground processing, DRIRU data is compensated by correcting the sign, scaling and rotating the data into the ACS references axes. Appendix F defines the

relationship between the DRIRU sensing axes and the ACS reference axes.

d. Gyro Drift Data--The drift calculation is performed by the OBC. Gyro drift parameters are updated asynchronously based on star sightings at up to once per minute. The data consist of a 32-bit two's-complement value for each axis (THETA BX, THETA BY, THETA BZ - See Table 21).

Gyro drift is calculated in the ACS reference axis coordinate system defined in Appendix F. Gyro drift must be subtracted from the compensated DRIRU data as a correction to calculate spacecraft attitude. The units of gyro drift rate are radians/512 ms. Gyro drift output data (in units of radians/512 ms) are calibrated at an LSB weight of 2^{-47}.

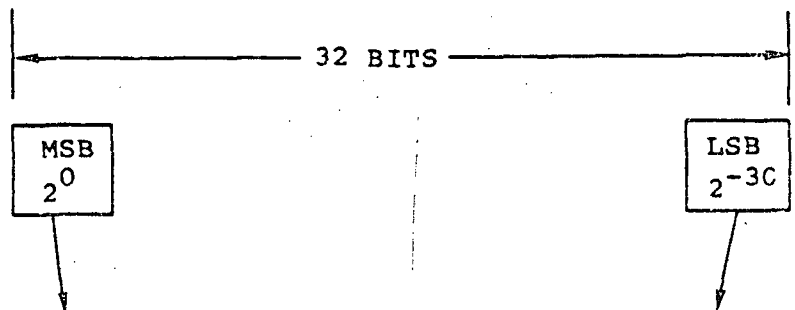
The format and frame position of the gyro drift binary scaled integer data is as follows:

		MSB 2^{-17}			LSB 2^{-47}
		SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
MINOR FRAME	THETA BX	16	17	18	19
	THETA BY	20	21	22	23
	THETA BZ	24	25	26	27

The data will appear in word 72 of minor frames 16 through 27 of PCD major frame zero. (See Figure 13.) Since the data will be sampled every 16.384 seconds, it will repeat at least three times between each calculation.

e. Attitude--The OBC calculates a flight segment attitude estimate every 512 milliseconds. The OBC will output one of eight sets of data in telemetry every 4.096 seconds (once a PCD major frame). Attitude is Euler parameters (i.e., EPA1, EPA2, EPA3, EPA4--see Table 21) that specify vehicle attitude relative to Earth-centered inertial frame (nondimensional). $EPA_{1,2,3,4}$ are components of the reference quaternion (as propagated from gyro data) which defines spacecraft attitude. Components 1 through 3 define the Eigen axis of rotation in ECI coordinates, and component 4 defines rotation about that axis, as shown in Figure 19.

Euler double precision words (36 bits) are compressed and scaled to 32 bits, 2's complement binary form as follows:



BIT ORDER SXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

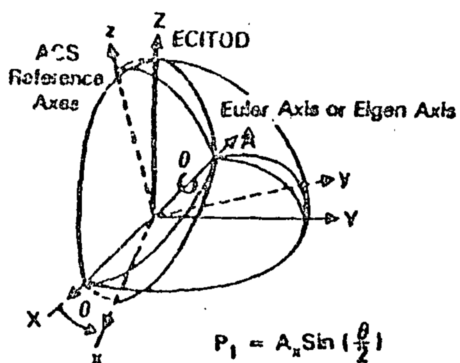
BYTE ORDER 0 1 2 3

The four compressed Euler Parameters (EP's) are output in word 72 of minor frames 0 through 15 of each PCD major frame. (See Figure 13.) The output sequence of EPA1 through EPA4 is as follows:

Content	PCD Minor Frame Numbers			
EPA1	0	1	2	3
EPA2	4	5	6	7
EPA3	8	9	10	11
EPA4	12	13	14	15
BYTE ORDER	1	2	3	4

- Quaternion Estimate of Attitude Control System (ACS) Reference Axes (Spacecraft Axes) with Respect to the ECITOD Axes
  - EPA1, EPA2, EPA3, EPA4 Given in Payload Correction Data
  - Estimate Given Every 4.096 Seconds
  - Includes Information from Star Trackers, Gyros and Gyro Drift Estimate
  - Accuracy Better than 0.01 Degrees (1σ)

- Definition



$$P_1 = A_x \sin\left(\frac{\theta}{2}\right)$$
$$P_2 = A_y \sin\left(\frac{\theta}{2}\right)$$
$$P_3 = A_z \sin\left(\frac{\theta}{2}\right)$$
$$P_4 = \cos\left(\frac{\theta}{2}\right)$$
$$P_i = EPA_i \cdot 2^{-30}$$

- Direction Cosines Matrix from the ACS Reference Axes to the ECITOD

$$\begin{bmatrix} P_1^2-P_2^2-P_3^2+P_4^2 & 2(P_1P_2-P_3P_4) & 2(P_1P_3+P_2P_4) \\ 2(P_1P_2+P_3P_4) & -P_1^2+P_2^2-P_3^2+P_4^2 & 2(P_2P_3-P_1P_4) \\ 2(P_1P_3-P_2P_4) & 2(P_2P_3+P_1P_4) & -P_1^2-P_2^2+P_3^2+P_4^2 \end{bmatrix}$$

$\hat{A} = \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$ is the Eigen axis

θ is the rotation angle about the Eigen Axis which defines the ACS reference axes

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Figure 19. Attitude Data

There are four attitude estimates in each PCD cycle. The time associated with attitude data contained within the PCD can be derived from the time code contained in words 96 through 102 of the first PCD major frame in the cycle. The derivation is as follows:

PCD Major-Frame Number	Time Computation
1	PCD time code - 4.096 seconds + 36 milliseconds
2	PCD time code + 36 milliseconds
3	PCD time code + 4.096 seconds + 36 milliseconds
4	PCD time code + 8.192 seconds + 36 milliseconds

In the normal operating mode, the OBC computed attitude, filtered to 1/2 Hz bandwidth, is output to provide a low-frequency reference attitude. The 4.096-second sample rate does not support reconstruction of this signal unless the frequency content turns out to be much lower than the filter allows. Gyro data are provided every 64 ms to contain 0-2 Hz frequency data and the ADS data, provided every 2 ms, contain frequencies up to 125 Hz. Since these sensors have different frequency responses, the data must be appropriately compensated to be combined.

f. Ephemeris--This calculation is made by the OBC. In this case, only 1 of 16 data sets will be output in the PCD (i.e., every other PCD major frame - 8.192 seconds).

Ephemeris consists of spacecraft position components (EOGBRF, Table 22) X, Y, and Z in meters and spacecraft velocity components (EGOBVF, Table 22) X, Y, and Z in meters per millisecond. Ephemeris is output as 32-bit binary words defining $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ in Earth-centered inertial true-of-date (ECITOD) coordinates. In the ECITOD

coordinate system, the Z-axis is along a line from the center of the Earth coincident with the true Earth spin axis, positive north. The X-axis is along a line from the center of the Earth toward the intersection of the true Equator and true ecliptic of date. The Y-axis completes the right-handed set. (The ECITOD system varies slowly with respect to a truly inertial system due to precession and nutation of the Earth's axis and precession of the plane of the ecliptic. These variations occur slowly enough that the ECITOD system can be considered to be inertial over a span of a few days for attitude control purposes.)

The ephemeris data are 36-bit double precision words that have been compressed to 32-bit, 2's complement form by dropping the second sign bit and the three LSB's. The format of these data is as follows:

<u>Position Components</u>

WORD 72   MSB 2^{22} LSB 2^{-8}

	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	
X	16	17	18	19	MINOR FRAME
Y	20	21	22	23	
Z	24	25	26	27	

Velocity Components

WORD 72 — MSB 2^{2} … LSB 2^{-28}

	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	
X	28	29	30	31	
Y	32	33	34	35	MINOR FRAME
Z	36	37	38	39	

The data will appear in word 72 of minor frames 16 through 39 of every other PCD major frame. (See Figure 15.) These major frames will carry the "1" and "3" identifier in place of time code.

There are two ephemeris estimates in each PCD cycle. The time associated with ephemeris data contained within the PCD can be derived from the time code contained in words 96 through 102 of the first PCD major frame in the cycle. The derivation is as follows:

PCD Major-Frame Number	Time Computation
1	time code + 36 milliseconds
3	time code + 8.192 seconds + 36 milliseconds

g. Fifty-six bits of spacecraft time code (seven 8-bit words) are inserted in the PCD stream. This code represents the start time for PCD major frame 0 and provides the timing reference for all data in the PCD cycle. The 56 bits of spacecraft time code are subcommutated into word 72 of minor frames 96 through 102 of the first PCD major frame of the PCD cycle. (See Figure 15.) The output sequence for the 56 time-code bits is contained in Table 9.

Table 9
Time Code Format in Payload Correction Data
(word 72 of minor frames 96 through 102
of the first PCD major frame in a cycle)

Minor-Frame Number	Words 72 Bits 0-7	Content of Word 72
96	0-3 4-7	Spacecraft ID Hundreds of days
97	0-3 4-7	Tens of days Units of days
98	0-3 4-7	Tens of hours Units of hours
99	0-3 4-7	Tens of minutes Units of minutes
100	0-3 4-7	Tens of seconds Units of seconds
101	0-3 4-7	Hundreds of milliseconds Tens of milliseconds
102	0-3 4-7	Units of milliseconds Fractions of milliseconds (LSB=1/16 millisecond)

Notes: Bits 0-7 = Two BCD words in format (MSB-LSB), (MSB-LSB).
Spacecraft ID are encoded as follows:
1110 = Landsat-4
1101 = Landsat-D'.

h. PCD Minor-Frame Sync--The same sync pattern used for the telemetry data will appear in words 0 through 2 of each PCD minor frame.

i. Minor-Frame Identification (MFID)--A 0 to 127 count of minor frames will appear in word 65 of each PCD minor frame (see Figure 17).

j. Major Telemetry Frame Identification--Word 72 of minor frames 96 through 103 of the second, third, and fourth PCD major frames of a four-frame set (Figure 15) will contain a unique identifier (1, 2, or 3).

k. TM Housekeeping Telemetry--A total of 248 bits of TM housekeeping telemetry data may be stripped out of the telemetry format by the OBC and sent to the formatter. The data will be transferred to the formatter 36 milliseconds after the start of each telemetry major frame. The data will be from the previous telemetry major frame.

The data will appear in word 72 of minor frames 16 through 46 of the third PCD major frame after the telemetry major-frame pulse. (See Figure 15.) This major frame will carry the identifier "2" in place of time code. The TM telemetry will consist of the following:

Word 72 of Minor Frame Number	Description
16	Blackbody temperature, °C
17	Silicon focal-plane assembly (FPA), °C
18	Calibration shutter flag temperature, °C
19	NASA use
20	Baffle temperature, °C
21	Cold focal-plane assembly monitor temperature, °K
22	NASA use
23	NASA use
24	Scan-line corrector temperature, °C
25	Calibration shutter hub temperature, °C
26	NASA use
27	NASA use
28	Relay optics temperature, °C
29	NASA use

Word 72 of Minor Frame Number	Description		Bit	Standard Mode
30	NASA use			
31	NASA use			
32	Serial Word B:			
		Band 1 On/Off	0	1
		Band 2 On/Off	1	1
		Band 3 On/Off	2	1
		Band 4 On/Off	3	1
		Band 5 On/Off	4	1
		Band 6 On/Off	5	1
		Band 7 On/Off	6	1
		Cold Stage Telemetry On/Off	7	1
33	NASA use			
34	Serial Word D:			
		Cal Lamp 1 On/Off	0	1
		Cal Lamp 2 On/Off	1	1
		Cal Lamp 3 On/Off	2	1
		Cal Lamp 1 Override On/Off	3	0
		Cal Lamp 2 Override On/Off	4	0
		Cal Lamp 3 Override On/Off	5	0
		Cal Sequencer On/Off	6	1
		Multiplexer Backup On/Off	7	1
35	Serial Word E:			
		NASA use	0	-
		NASA use	1	-
		Blackbody On/Off	2	1
		Blackbody T2 On/Off	3	0
		Blackbody T3 On/Off	4	1
		Blackbody Backup On/Off	5	0

Word 72 of Minor Frame Number	Description		Bit	Standard Mode
		SME 1 On/Off - see Note 1	1	1
		SME 2 On/Off - see Note 1	7	0
36	Serial Word F:			
		NASA use	0	-
		NASA use	1	-
		NASA use	2	-
		NASA use	3	-
		NASA use	4	-
		NASA use	5	-
		Multiplexer On/Off	6	1
		Midscan Pulse On/Off (Primary) - see Note 4	7	0
37	Serial Word G:			
		Scan Line Corrector 1 On/Off	0	1
		Scan Line Corrector 2 On/Off	1	0
		Cal Shutter On/Off	2	1
		Cal Shutter Phase Lock Y/N - see Note 2	3	1
		Cal Shutter Amplitude Lock Y/N - see Note 2	4	1
		Backup Shutter On/Off	5	0
		Backup Shutter Phase Lock Y/N	6	0
		Backup Shutter Amplitude Lock Y/N	7	0
38	NASA use			
39	Serial Word L:			
		DC Restore Normal/Not Normal	0	1
		Frame DC Restore Selected Y/N	1	0

Word 72 of Minor Frame Number	Description	Bit	Standard Mode
	Telemetry Scaling On/Off - see Note 3	2	1
	NASA use	3	-
	NASA use	4	-
	Midscan Pulse Backup On/Off - see Note 4	5	0
	SME 1 Select SAM - see Note 1	6	1
	NASA use	7	-
40	Primary mirror temperature, °C		
41	NASA use		
42	Secondary mirror temperature, °C		
43	NASA use		
44	NASA use		
45	NASA use		
46	NASA use		

Notes concerning serial words:

[1] If scan mirror electronics 2 (SME-2) is selected, then
Serial Word E -- Bit 6=0
Serial Word E -- Bit 7=1
Serial Word L -- Bit 6=0

[2] CAL shutter amplitude lock (Serial Word G -- Bit 4=1) indicates that the shutter is moving with the correct amplitude.

CAL shutter phase lock (Serial Word G -- Bit 3=1) indicates that the phasing between the shutter and scan mirror is correct.

Both phase and amplitude lock must be present or shutter may interfere with the image data.

[3] If telemetry scaling (Serial Word L -- Bit 2=0) is off, then blackbody, baffle and silicon focal plane temperatures are invalid.

[4] If midscan pulse (Serial Word F -- Bit 7=1) or midscan pulse backup (Serial Word L -- Bit 5=1) are on, midscan code will be injected into the image data at midscan.

The TM housekeeping telemetry in the PCD cycle was sampled at the PCD time code for the cycle minus 16.316 seconds.

Each telemetry function can be converted from counts (C's) to engineering units (EU's) by using the following equation:

$$EU = A_0 + A_1C + A_2C^2 + A_3C^3 + A_4C^4 + A_5C^5$$

The units and coefficients for each telemetry point follow.

Blackbody temperature: degrees centigrade

$A_0 = 12.44$ $A_1 = 0.1326$ $A_2 = -0.1604 \times 10^{-4}$
$A_3 = 0.1416 \times 10^{-5}$ $A_4 = -0.6519 \times 10^{-8}$ $A_5 = 0.1812 \times 10^{-10}$

Silicon FPA temperature: degrees centigrade

$A_0 = 8.992$ $A_1 = 0.1011$ $A_2 = -0.1595 \times 10^{-4}$
$A_3 = 0.3605 \times 10^{-6}$ $A_4 = 0.0$ $A_5 = 0.0$

Calibration shutter flag temperature: degrees centigrade

$A_0 = 35.37$ $A_1 = -0.1670$ $A_2 = 0.1404 \times 10^{-3}$
$A_3 = -0.3630 \times 10^{-6}$ $A_4 = 0.0$ $A_5 = 0.0$

Baffle temperature: degrees centigrade

$A_0 = -4.040$ $A_1 = -0.3913$ $A_2 = -0.7061 \times 10^{-2}$
$A_3 = 0.6710 \times 10^{-4}$ $A_4 = -0.2671 \times 10^{-6}$ $A_5 = 0.3701 \times 10^{-9}$

Cold stage FPA temperature: degrees Kelvin

$A_0 = 110.0$ $A_1 = -0.1000$ $A_2 = 0.0$
$A_3 = 0.0$ $A_4 = 0.0$ $A_5 = 0.0$

Scan-line corrector: degrees centigrade

$A_0 = 120.6$ $A_1 = -1.899$ $A_2 = 0.01918$
$A_3 = -0.1191 \times 10^{-3}$ $A_4 = 0.3789 \times 10^{-6}$ $A_5 = -0.4907 \times 10^{-9}$

Calibration shutter hub temperature: degrees centigrade

$A_0 = 120.6$ $A_1 = -1.899$ $A_2 = 0.01918$
$A_3 = -0.1191 \times 10^{-3}$ $A_4 = 0.3789 \times 10^{-2}$ $A_5 = 0.4907 \times 10^{-9}$

Relay optics temperature: degrees centigrade

$A_0 = -121.23$ $A_1 = -1.9147$ $A_2 = 0.014275$
$A_3 = 0.11865 \times 0^{-3}$ $A_4 = 0.37343 \times 10^{-6}$ $A_5 = -0.47899 \times 10^{-9}$

Primary mirror temperature: degrees centigrade

$A_0 = -121.23$ $A_1 = -1.9147$ $A_2 = 0.014275$
$A_3 = 0.11865 \times 10^{-3}$ $A_4 = 0.37343 \times 10^{-6}$ $A_5 = -0.47899 \times 10^{-9}$

Secondary mirror temperature: degrees centigrade

$A_0 = -121.23$ $A_1 = -1.9147$ $A_2 = 0.014275$
$A_3 = 0.11865 \times 10^{-3}$ $A_4 = 0.37343 \times 10^{-6}$ $A_5 = -0.47899 \times 10^{-9}$

Note: Telemetry conversions can change and are instrument unique.

l. Spare Telemetry--Up to 176 bits of telemetry data may be stripped out and output in telemetry in the same manner as the TM housekeeping data.

The data will appear in word 72 of minor frames 28 through 49 of the first PCD major frame after the telemetry major-frame pulse. (See Figure 15.) This major frame carries the spacecraft time code.

The data will be from the telemetry major frame that started 32.768 seconds betore the time given in the PCD major frame.

At present, four 8-bit words have been defined as shown in Table 9a.

m. Frame Error--A "Frame Error Bit" is transmitted as the MSB of word 72 of minor frame 116 of each PCD major frame (see Figure 16). A digital zero indicates that the expected telemetry major frame pulse either did not occur or did not line up with the start of the first PCD major frame.

n. A/D Ground Reference--The output of the Angular Displacement Sensor Assembly (ADSA) A/D Converter for a grounded input is transmitted in word 72 of minor frames 116 and 117 of each PCD major frame (Figure 16).

Table 9a
Spare Telemetry in PCD Subcom (Word 72)

Minor Frame	Function		
28	Ephemeris Source Identification	$(00)_{16}$ = GPS $(01)_{16}$ = Uplink	
29	Roll Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below
30	Pitch Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below
31	Yaw Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below

IRU Channel

	Gyro 1	Gyro 2
Roll	B	A
Pitch	B	C
Yaw	A	C

5.4.8 High-Resolution Data

The high-resolution sensor data usually follows the PCD word and completes the minor frame. The format is always 96 8-bit words unless preempted by the next SLS. During the first six minor frames following the SLS, these data slots are taken up with time code information. All time, picture, and calibration data words are PN-encoded.

5.4.9 TM Time Code

The TM time code information contained in the first six minor frames after scan-line start represents the time of the scan-line start. Time code minor frames contain 102 8-bit words. The first four words are dedicated to minor-frame sync. The minor-frame sync word is:

```
MSB (output first)
0000  0010  0011  0111  0001  0110  1101  0001
                                           LSB
```

Time is binary-coded decimal (BCD) days and Greenwich mean time (GMT) hours, minutes, seconds, milliseconds, and 1/16 millisecond. A 4-bit spacecraft identifier is included within the time code. Table 8 shows the output format of the first six minor frames of each major frame (i.e., set of 16 scan lines).

5.4.10 Midscan Code Format

If enabled by command, a midscan code will replace portions of the data in the last 96 words of a scene data minor frame. The midscan code consists of 48 words of white (level 255) data followed by 48 words of black (level 0) data. The midscan code will start within two to nine words of the second scan-angle monitor pulse following scan-line start, which will occur approximately in minor frame 3160. The midscan code can interrupt

scene data at word boundaries and need not be coherent with a minor frame. In most cases, the midscan code will occupy portions of two minor frames. The midscan code does not replace minor-frame sync, Band 6, and PCD words. Midscan code data are PN-encoded, have the four LSB's inverted, and are output MSB first. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements. Upon special request, foreign ground stations could receive MSS or TM imagery with midscan code enabled. For TM, this is unnecessary because first half scan time error and second half scan time error is included in the line length code described in Section 5.4.13. This line length code is part of the X-band data.

5.4.11 End of Scan

Insertion of this end-of-scan code will allow determination of end of scan by ground processing systems. When the end-of-scan pulse occurs, approximately 6320 minor frames into the major frame, the TM will generate 48 words of dark (level 0), followed by 48 words of bright (level 255), 48 words of dark, and 48 words of bright in sequence. These words will replace the high-resolution data in the current minor frames but not the minor-frame sync, Band 6 sensor, or PCD. The first bit of end-scan code occurs within two to nine word times of the TM mirror scan-angle monitor pulse. The end-scan code is not coherent with the minor frame, but does start on an 8-bit word boundary. It replaces scene data as required, but does not replace minor-frame sync, Band 6, and PCD or frame-counter words. The 192 words of end-scan code will sually occupy portions of three minor frames. End-scan code data are PN-encoded, four LSB's inverted, and output MSB first.

5.4.12 Line-Length Data

The TM high-rate data stream contains a line-length code that indicates the time from line start to midscan, the time from midscan to line stop, and scan direction. The line-length data appearing in a scan is for the previous scan.

The scan mirror assembly transmits a 32-bit serial data word to the multiplexer at the end of each scan (Figure 8). In the scan angle monitor mode, the data are as shown in Figure 20. As indicated, each bit of the 32-bit line-length code is repeated 47 times and encoded in six consecutive 8-bit bytes (48 bits total).

The units of magnitude are clock pulses where the clock rate is 1/16 the TM 84.903 bit rate. Minus magnitudes are given in 2's complement notation.

SHSERR = time error in clock counts from the nominal midscan to line stop count of 161,165

FHSERR = time error in clock counts from the nominal line start to midscan count of 161,164

For example, a typical engineering model sample is:

000000100100	111111011101	00000000
Decimal = 36	Decimal = -35	Reverse

SHSERR = (36) (1/(84.903/16)) = 6.78 microseconds
FHSERR = (-35) (1/(84.903/16)) = -6.60 microseconds

Active scan time = ((161,165 + 161,164) + (SHSERR + FHSERR))
x (1/(84.903/16)) = 60,743 microseconds

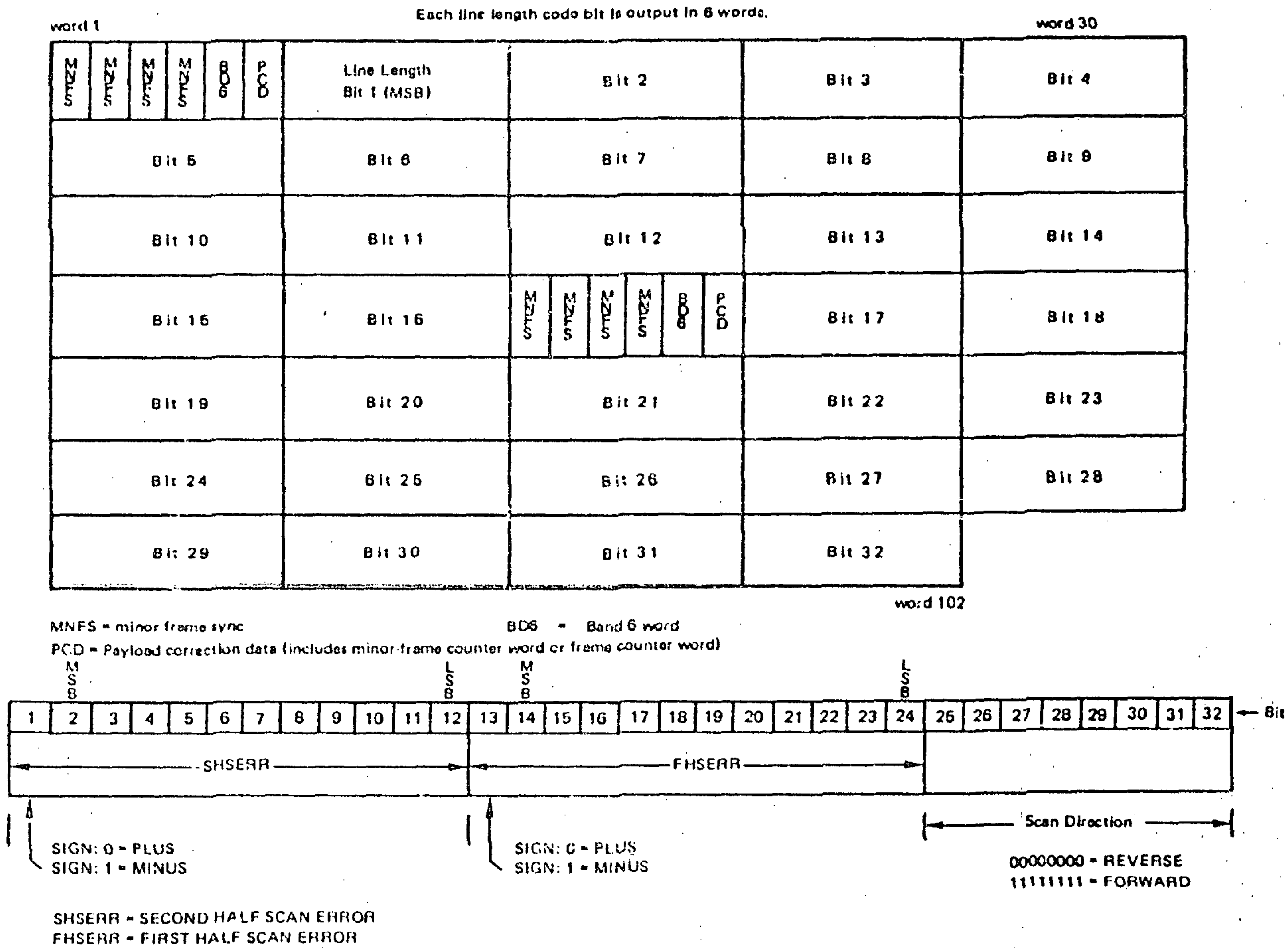

Figure 20. Line-Length Format

5.4.13 DC Restore and Calibration Data

After transmission of the line length and the scan direction data, sensor data will be output until the sinusoidally oscillating shutter obscures the optical path to the detectors. During this period, the internal calibration and dc restoration data are transmitted as described in Paragraph 5.3. Table 7 provides approximate start- and end-time periods when calibration and dc restoration occur for both the forward and reverse scans. Refer to Table 7 for minor-frame shutter obscuration timing.

5.4.14 Postamble Data

Postamble data commence at the 960th minor frame following end-scan code. Postamble will continue for approximately 1 millisecond, until it is interrupted by major-frame sync. Major-frame sync will interrupt only at word boundaries. Postamble minor frames contain the standard minor-frame sync (4), Band 6 data, and PCD words. The remaining words of each minor frame shall contain the inverse of the PN-code shown in Figure 9. The inverse PN-code data are not encoded. The PN data start with the 49th bit of the pattern and are reset at each minor frame. (Refer to Table 6 for a list of timing and minor-frame word counts for postamble.)

5.5 TM DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix C.

6. TELEMETRY FORMAT

For Landsat-4, there will be two fixed telemetry formats, one engineering format, and one mission format. Both formats can operate at 1 kbps or 8 kbps. The mission format will be transmitted to ground stations at 8 kbps. A minor telemetry frame

consists of 1024 bits that represent 128 8-bit words. Sixteen of the 128 words are in a fixed position and are located symmetrically in the format as four groups of four words each. A major frame consists of 128 minor frames.

6.1 REAL-TIME TELEMETRY AND PAYLOAD CORRECTION DATA FORMATS FOR GSTDN BACKUP STATIONS AND FOREIGN GROUND STATIONS

The real-time spacecraft telemetry (i.e., housekeeping and OBC data reports) and the PCD are downlinked by the S-band transponder. The foreign ground stations can use either the real-time spacecraft telemetry or the PCD only, or they may use both. The data control and formats of these two data types are described in Section 7 and Section 5.4.7, respectively. (Refer to Paragraph 9.4 for the S-band omni downlink characteristics.)

6.2 BIT RATE

The output bit rates for direct telemetry data transmission to Ground Spaceflight Tracking and Data Network (GSTDN) and foreign ground stations are shown in Table 10.

6.3 MODULATION TECHNIQUE

The real-time spacecraft telemetry is biphase-M phase-shift keyed, pulse-modulated (BIΦ-M/PSK/PM) on a 1.024-MHz subcarrier by the omni antenna. Twenty percent of the power is in the residual carrier. The PCD is BIΦ-M/PM directly on the base band. The biphase-M and NRZ data formats are described and shown in Table 11.

Table 10
Telemetry Bit Rates

Telemetry Type	Bit Rate (kbps)	Receiving Site
Real-time spacecraft telemetry	8	GSTDN or foreign stations
Payload correction data	32	GSTDN or foreign stations

Table 11
Data Bit Stream Formats

Data Format	...11001...	Description
NRZ-L		NRZ level (or NRZ change): "ONE" is represented by one level. "ZERO" is represented by the other level.
NRZ-M		NRZ-mark (differential encoding): "ONE" is represented by a change in level. "ZERO" is represented by no change in level.
BIφ-M		Biphase, a transition occurs at the beginning of every time (T) period. "ONE" is represented by a second transition one-half time period later. "ZERO" is represented by no second transition.

6.4 WORD LENGTH

The word length is 8 bits assembled into analog, passive analog, bilevel (discrete), or serial digital.

6.5 FORMATS

Three formats are supported by Landsat-4: Format I (engineering), Format II (mission), and Format III (OBC dump). The

mission format is to be used by GSTDN and foreign stations in the normal on-orbit payload activity. The engineering format is to be used by NASA when the spacecraft is deployed in an orbit-adjust or safe-hold activity, and the OBC dump is to be used by NASA to maintain and verify OBC software.

7. MISSION FORMAT TELEMETRY

This section describes the Landsat-4 Mission telemetry data to be provided to the foreign ground stations.

7.1 TELEMETRY FRAME FORMAT

Table 12 presents the minor-frame word (column) allocations for the mission format. Each minor-frame word is sampled every 128 milliseconds at 8 kbps. Ten minor-frame words (i.e., columns 0, 1, 2, 3, 34, 35, 64, 65, 66, and 67) are reserved for specific spacecraft data and are designated as fixed words. Six words (i.e., 32, 33, 96, 97, 98, and 99) have been allocated for sub-commutated data so that data are sampled at least once every major frame. Twenty-five additional words in each minor frame (i.e., columns 91 to 95 and 108 to 127) have been reserved for OBC reports.

7.2 TELEMETRY FORMAT

7.2.1 Major Frame

The major-frame telemetry format is a 128- by 128-column matrix. A minor frame (row) contains 128 8-bit words (columns) and is shown in Table 12. A major frame consists of 128 minor frames. The format starts in row 0, column 0 and proceeds sequentially through the matrix until the final word in row 127, column 127 is transmitted, thus completing a major frame. The MSB is transmitted first in a minor-frame word. The major-frame duration is 16.384 seconds at 8 kbps.

Table 12
Mission Format Telemetry Matrix Construction

WORD NUMBER →

MAJOR FRAME FORMAT

MINOR FRAME NUMBER	0	1	2	3	4...31	32	33	34	35	36...63	64	65	66	67	68...95	96	97	98	99	100...127
	FIXED WORDS							FIXED WORDS			FIXED WORDS									
0, 1, 2 ... 127	MINOR FRAME SYNC (24 BITS)			TLM FORMAT RATE & ID		128 DEEP SUBCOMS 01	02	RECEIVER STATUS	OBC DATA WORD ID		SPACECRAFT CLOCK 8 LSBS	FRAME COUNTER	COMMAND COUNTER OF SELECTED CU	DWELL MODE & DWELL ID		128 DEEP SUBCOMS				

7.2.2 Minor Frame

Each minor frame contains 128 words. The first three words are used for the minor-frame synchronization. The minor-frame counter is located in word location 65. These data words are located in fixed word locations as shown in Table 12. At the 8-kbps rate, a word period is 1 millisecond.

7.2.3 Telemetry Control Words

7.2.3.1 Synchronization--The first three words in each minor frame are used for minor-frame synchronization. These 24 sync bits are described as follows:

WORD 0 MSB	WORD 1	WORD 2 LSB
11111010	11110011	00100000

Since the telemetry bit stream is transmitted MSB first, this sync pattern is received as shown. In hexadecimal, the sync pattern is $FAF320_{16}$.

7.2.3.2 Frame Counter--Word 65 of the minor frame is the frame counter. At the end of each minor frame, the counter is incremented by one, and the new value (n+1) is placed in word 65 in the subsequent minor-frame counter location. This process is continued until a maximum count of 255 is reached and the process is repeated. Only the seven LSB's are needed to determine the frame-counter contents for subcom word ID (0 to 127). The bit pattern sequence is shown in Figure 17.

7.2.3.3 Other Control Words--There are two other control words in each telemetry minor frame that may be required in ground

processing. The contents of these words are described below and in the following paragraphs:

a. Word 3

(1) Bit rate (bits 0, 1, and 2):

000 = 1 kbps (engineering use only)
011 = 8 kbps (normal use)

(2) Format ID (bits 3 and 4):

01 = format I (engineering), for NASA use only
10 = format II (mission)
11 = OBC controlled, for NASA use only

(3) Real-time computer data dump (bit 6)

0 = OBC dump, for NASA use only
1 = real-time spacecraft/normal payload operation

b. Word 35 - Computer Data Word ID (8 bits)--Identifies the OBC report number contained in this minor frame. The 25-word OBC contribution to telemetry minor-frame word locations 91 to 95 and 108 to 127 can be identified by this means.

7.2.3.4 Subcommutation Mission Format--There are a total of 31 subcommutated words in a minor frame: 6 normal and 25 OBC words. The length of the subcommutation cycle is one full major frame. The 7-bit (0 to 127) minor-frame counter contained in word 65 is used to identify subcom words 32, 33, and 96 through 99. Words may be sampled in these columns one or more times per major frame. For example, a telemetry word assigned a sample rate of once per major frame will be sampled approximately once every 16

seconds at 8 kbps. Those words that require sampling faster than once per major frame have been equally spaced in subcom columns. As an example, a word requiring four samples per major frame is sampled first in minor frames N, second in minor-frame N+32, third in N+64, and fourth in N+96. The OBC reports contained in words 91 to 95 and 108 to 127 are subcommutated as a group, and are indexed to the OBC report number contained in word 35.

7.2.3.5 Nonfixed Columns--There are 112 other columns in the mission format for the assignment of subsystem telemetry data.

7.2.4 Telemetry Assignments by User

Tables 13 through 19 list the telemetry data of interest to Landsat-4 ground station operators. Table 13 gives a telemetry function description and location in the telemetry matrix for data sampled in each minor frame, and Tables 14 through 19 cover the six subcommutators. See Section 8 for a description of the contents of OBC reports.

8. ONBOARD COMPUTER REPORTS

The OBC contributes 128 reports to each telemetry major frame and 1 report to each telemetry minor frame. The length of the reports are mission unique, but must be at least two words long. The first word is output in column 35 and gives the report number; the remaining word or words give the data being reported. The Landsat-4 flight software contributions to telemetry are presented in this section. The OBC data items contained in the telemetry stream and their output rates are listed along with the format of the reports as they appear in the telemetry minor frames.

The number of OBC reports generated by the various flight elements, as well as the rate at which the reports are output per

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Table 13
Mission Telemetry Frame Format

Minor Frame Word	Description	Minor Frame Word	Description	Minor Frame Word	Description
00	Minor frame sync word 00	43		85	
01	Minor frame sync word 01	44	Calibration lamp 1 current	86	
02	Minor frame sync word 02	45	Calibration lamp 2 current	87	
03	Telemetry rate, format, ID	46	Calibration lamp 3 current	88	
04		47	Blackbody temperature	89	
05		48	Silicon focal plane assembly (FPA) temperature	90	
06		49	Calibration shutter temperature	91	OBC data word 1
07		50	Backup shutter temperature	92	OBC data word 2
08		51	Cold stage FPA temperature	93	OBC data word 3
09		52	SLC temperature	94	OBC data word 4
10		53	Baffle temperature	95	OBC data word 5
11		54		96	Subcommutation 03
12		55		97	Subcommutation 04
13		56		98	Subcommutation 05
14		57		99	Subcommutation 06
15		58		100	
16		59		101	
17		60		102	
18		61		103	
19		62		104	
20		63		105	
21		64		106	
22		65	Minor-frame counter	107	
23		66		108	OBC data word 6
24		67		109	OBC data word 7
25		68		110	OBC data word 8
26		69		111	OBC data word 9
27		70		112	OBC data word 10
28		71		113	OBC data word 11
29		72		114	OBC data word 12
30		73		115	OBC data word 1[illegible]
31		74		116	OBC data word 14
32	Subcom 01	75		117	OBC data word 15
33	Subcom 02	76		118	OBC data word 16
34		77		119	OBC data word 17
35	OBC data identifier	78		120	OBC data word 18
36		79		121	OBC data word 19
37		80		122	OBC data word 20
38		81		123	OBC data word 21
39		82		124	OBC data word 22
40		83		125	OBC data word 23
41		84		126	OBC data word 24
42				127	OBC data word 25

Table 14
Subcommutator 01--Minor Frame Word 32

Minor Frame	Description	Minor Frame	Description
00	Time-code word 1	33	
01	Time-code word 2	⋮	
02	Time-code word 3	50	Calibration lamp 3 current
03	Time-code word 4	⋮	
04	Time-code word 5		
05	Time-code word 6	74	Blackbody temperature
06	Time-code word 7	75	Silicon focal-plane assembly temperature
07		⋮	
08			
09		78	Calibration shutter flag temperature
10		79	Calibration shutter hub temperature
11		⋮	
12	Calibration lamp 1 current		
13		87	Baffle temperature
14		⋮	
15			
16		89	Cold focal-plane assembly monitor temperature
17	All calibration lamps on		
18		⋮	
19			
20		92	Relay optics temperature
21		⋮	
22			
23		98	Primary mirror temperature
24		⋮	
25			
26		100	Secondary mirror temperature
27		⋮	
28		112	Scan-line corrector temperature
29		⋮	
30			
31	Calibration lamp 2 current		
32		128	

Table 15
Subcommutator 02—Minor Frame Word 33

Minor Frame	Description	Minor Frame	Description
00		33	
01		34	
02		35	
03		36	
04		37	
05		38	
06		39	MSS band 1 channel A video (analog voltage monitor for detector 1)
07			
08		40	
09		41	
10		42	
11		43	
12		44	
13		45	MSS band 2 channel A video (detector 7)
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	MSS band 3 channel A video (detector 13)
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	MSS band 4 channel A video (detector 19)
26			
27			
28			
29			
30			
31		128	
32			

Table 16
Subcommutator 03-Minor Frame Word 96

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 706 = MSS system power A on/off (bit 0) MSS system power B on/off (bit 1)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

Table 17
Subcommutator 04--Minor-Frame Word 97

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 801: MSS multiplexer COMPRESSED/LINEAR (Bit 6)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

Table 18
Subcommutator 05--Minor-Frame Word 98

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 802: MSS band 1 gain HIGH/LOW (bit 0) MSS band 2 gain HIGH/LOW (bit 1) MSS band 1 low voltage ON/OFF (bit 2) MSS band 2 low voltage ON/OFF (bit 3) MSS band 3 low voltage ON/OFF (bit 4) MSS band 4 low voltage ON/OFF (bit 5)	27 ↓	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26		128	

Table 19
Subcommutator 06--Minor-Frame Word 99

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 803: MSS high voltage ON/OFF (bit 0) MSS band 1 high voltage A ON/OFF (bit 1) MSS band 1 high voltage B ON/OFF (bit 2) MSS band 2 high voltage A ON/OFF (bit 3) MSS band 2 high voltage B ON/OFF (bit 4) MSS band 3 high voltage A ON/OFF (bit 5) MSS band 3 high voltage B ON/OFF (bit 6)	26	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25		128	

major frame, is tabulated in Table 20 and Figures 21 through 28. The "Samples/Major-Frame" (Tables 21 and 22) column contains the total reports contributed by each processor to each major frame. The Landsat-4 flight software will contribute 103 reports to each major frame of telemetry, 17 of which are useful in ground processing of image data. This leaves 25 reports as a reserve for growth in the number of OBC data items contributed to telemetry. Each report will be 25 words long. The rate at which the various reports are output ranges from one to eight times per major frame. The order in which the OBC reports are output is defined in Table 20. The ACS telemetry is given in Table 21 and Figures 21 through 27. The ephemeris computation telemetry report is given in Figure 28 and Table 22. Most of the data in Reports 1, 2, 8, 9, 10, and 11 are intended primarily for operation of the spacecraft and for engineering purposes. Ephemeris and attitude data in the OBC reports are the same as in the PCD subcom except for sampling and scaling. The epoch for the attitude estimates (ACS Telemetry Reports 1 and 2), gyro compensation data (ACS Telemetry Report 10) and ephemeris (Ephemeris Computation Telemetry Report 1) is defined by the parameter T_f in ACS Report No. 11.

The relationship between these reports and T_f is as defined below:

Minor frame containing T_f	Minor frames containing reports for epoch T_f
30	8, 9, 16, 27
62	40, 41, 48
94	72, 73, 80
126	104, 105, 112

Gyro data in ACS Telemetry Report 12 are also related to T_f, as explained below.

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Table 20
Onboard Computer Telemetry Report Sequence

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
0				
1				
2				
3				
4				
5				
6				
7				
8	1	Attitude control system (ACS) telemetry report	1	See Fig. 21
9	2	ACS telemetry report	2	See Fig. 22
10				
11				
12				
13				
14				
15	12	ACS telemetry report	12	See Fig. 27
16	13	Ephemeris computation telemetry report	1	See Fig. 28
17				
18				
19				
20				
21				
22				
23	8	ACS telemetry report	8	See Fig. 23
24				
25				
26	9	ACS telemetry report	9	See Fig. 24
27	10	ACS telemetry report	10	See Fig. 25
28				
29				
30	11	ACS telemetry report	11	See Fig. 26
31	12	ACS telemetry report	12	
32				
33				

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Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
34				
35				
36				
37				
38				
39				
40	1	ACS telemetry report	1	
41	2	ACS telemetry report	2	
42				
43				
44				
45				
46				
47	12	ACS telemetry report	12	
48	13	Ephemeris computation telemetry report	1	
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62	11	ACS telemetry report	11	
63	12	ACS telemetry report	12	
64				
65				
66				
67				
68				
69				
70				
71				
72	1	ACS telemetry report	1	
73	2	ACS telemetry report	2	
74				
75				

Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
76				
77				
78				
79	12	ACS telemetry report	12	
80	13	Ephemeris computation telemetry report	1	
81				
82				
83				
84				
85				
86				
87				
88				
89				
90				
91				
92				
93				
94	11	ACS telemetry report	11	
95	12	ACS telemetry report	12	
96				
97				
98				
99				
100				
101				
102				
103				
104	1	ACS telemetry report	1	
105	2	ACS telemetry report	2	
106				
107				
108				
109				
110				
111	12	ACS telemetry report	12	
112	13	Ephemeris computation telemetry report	1	
113				
114				
115				
116				
117				

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Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
118				
119				
120				
121				
122				
123				
124				
125				
126	11	ACS telemetry report	11	
127	12	ACS telemetry report	12	

Gyro data (CNGX, CNGY, CNGZ) used by NASA for MSS processing are provided in ACS Telemetry Report 12. The three samples (three gyro axes) in a set are sampled simultaneously, and each report contains four sets sampled at 0.512-second intervals. The first set within the report that occurs in minor frame 15 corresponds to a time 0.512 second before the time T_f which appears within (ACS Telemetry Report 11) minor frame 30. The data continue uniformly at 0.512-second intervals. These gyro data are uncompensated (alignment, bias, and scale factor errors are not corrected) and may be filtered or unfiltered. A presampling filter is available and if in use, FLTROFF in ACS Telemetry Report 8 is set to 1. The filter has unity dc gain and a break frequency of approximately 0.5 Hz. This filter is not currently being used; if plans to use it develop, additional information will be provided.

Normal spacecraft configuration for imaging is Earth pointing with inertial reference and the gyros in the low-rate mode. Parameters defining this configuration are defined in Table 21 and should be verified from telemetry to assure normal image acquisition.

TLM Word	1	2	3	4	5
OBC Data	MSB θ_x	LSB	MSB θ_Y	LSB	θ_z MSB

6	7	8	9	10
θ_z LSB				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output four times per major frame in minor frames 8, 40, 72, and 104.
Sixteen MSB's of double precision θx, θy, θz are downlinked.

Figure 21. ACS Telemetry Report 1

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TLM Word	1	2	3	4	5
OBC Data				Wx	Wy

6	7	8	9	10
Wz	Ex		Ey	

11	12	13	14	15
Ez		EPA1		

16	17	18	19	20
EPA2			EPA3	

21	22	23	24	25
EPA3	EPA4			

Output four times per major frame in minor frames 9, 41, 73, and 105.
Eight MSB's of single precision Wx, Wy, Wz are downlinked.
Sixteen MSB's of double precision Ex, Ey, Ez, are downlinked.

Figure 22. ACS Telemetry Report 2

TLM WORD	1	2	3	4	5
OBC DATA	MODE				

6	7	8	9	10
		FLTROFF		

11	12	13	14	15

16	17	18	19	20
		ICAL		

21	22	23	24	25

Figure 23. ACS Telemetry Report 8

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TLM WORD	1	2	3	4	5
OBC DATA					

6	7	8	9	10

11	12	13	14	15
			SENSTA	

16	17	18	19	20

21	22	23	24	25

Figure 24. ACS Telemetry Report 9

TLM Word	1	2	3	4	5
OBC Data	MSB θ_{bx}	LSB	MSB θ_{by}	LSB	MSB θ_{bz}

6	7	8	9	10
θ_{bz} LSB				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output once per major frame in minor frame 27.
Sixteen MSB's of double precision θbx, $\theta$by, θbz are downlinked.

Figure 25. ACS Telemetry Report 10

TLM Word	1	2	3	4	5
OBC Data	MSB ← T_f				→

6		7	8	9	10
→ LSB	XXXXX				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output four times per major frame in minor frames 30, 62, 94, and 126.

Notes

1) Each value of the T_f in OBC Report ACS 11 defines an epoch at which gyro data is sampled, ephemeris data is computed, and attitude is computed.

Scale = 38, Length = 42 bits preceded by sign bit, and LSB = 1/16 millisecond

The four ACS 11 reports in each major frame correspond to the four Ephemeris report sets and the other ACS reports sampled four times per major frame.

2) T_f is the GMT milliseconds into the year as derived from the DPU clock, referenced to a value of 8.64×10^7 msec at 0000 hours GMT on January 1.

Figure 26. ACS Telemetry Report 11

TLM WORD	1	2	3	4	5
OBC DATA	$CNGX_0$		$CNGY_0$		$CNGZ_0$

TLM WORD	6	7	8	9	10
OBC DATA		$CNGX_1$		$CNGY_1$	

TLM WORD	11	12	13	14	15
OBC DATA	$CNGZ_1$		$CNGX_2$		$CNGY_2$

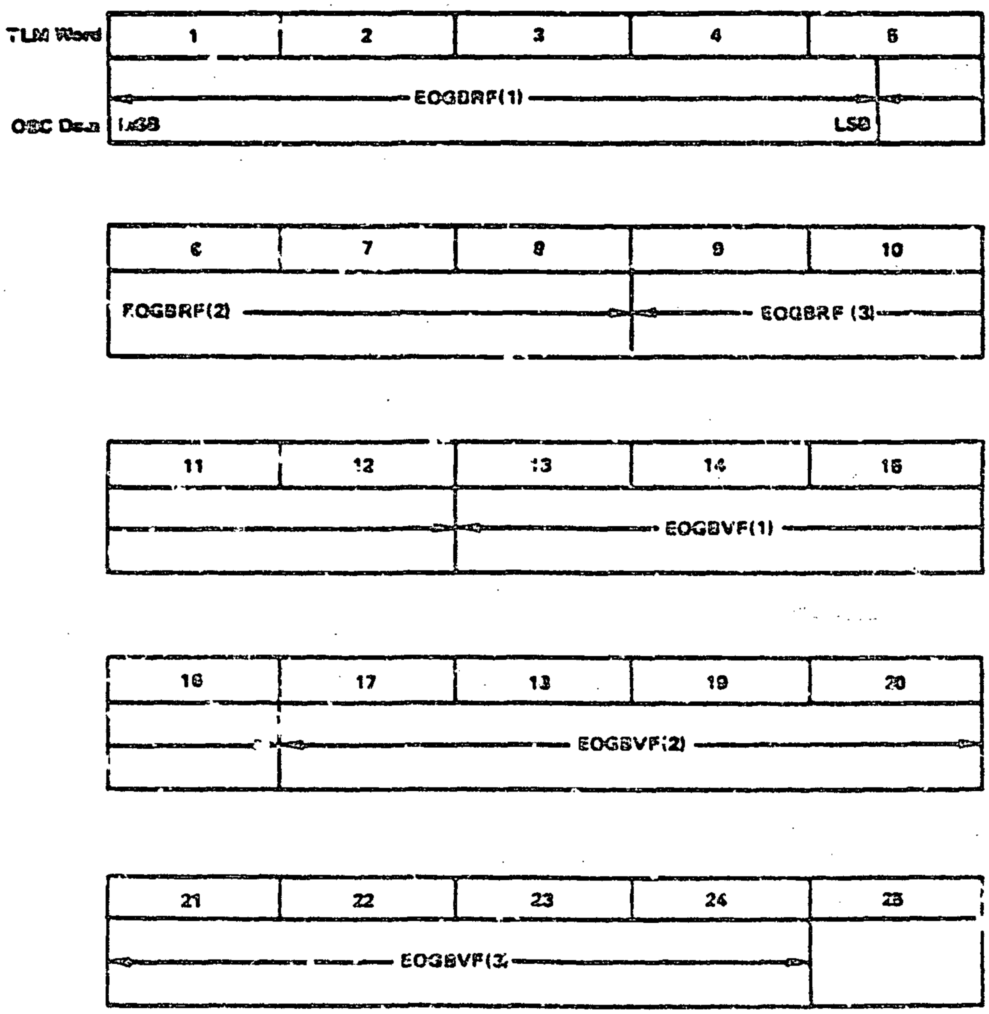
TLM WORD	16	17	18	19	20
OBC DATA		$CNGZ_2$		$CNGX_3$	

TLM WORD	21	22	23	24	25
OBC DATA	$CNGY_3$		$CNGZ_3$		

FOUR SETS OF GYRO DATA PROVIDED:

(1) $CNGX_0$, $CNGY_0$, $CNGZ_0$
(2) $CNGX_1$, $CNGY_1$, $CNGZ_1$
(3) $CNGX_2$, $CNGY_2$, $CNGZ_2$
(4) $CNGX_3$, $CNGY_3$, $CNGZ_3$

Figure 27. ACS Telemetry Report 12



Output four times per major frame in minor frames 16, 48, 80, and 112.

Figure 28. Ephemeris Computation Telemetry Report 1

Table 21
ACS Telemetry

Symbol	Definition	OBC Report	Samples/ Major Frame	Number of Bytes	Range	Unit	LSB Weight
θ_x	Roll axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
θ_y	Pitch axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
θ_z	Yaw axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
W_x	Roll axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
W_y	Pitch axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
W_z	Yaw axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
E_x	Roll attitude error	2	4	2	±3.0000	rad	$1/2^{13}$
E_y	Pitch attitude error	2	4	2	±3.0000	rad	$1/2^{13}$
E_z	Yaw attitude error	2	4	2	±3.0000	rad	$1/2^{13}$
EPA 1		2	4	3	±2	ND	$1/2^{22}$
EPA 2	Euler parameters that specify vehicle orientation relative to Earth-centered inertial frame	2	4	3	±2	ND	$1/2^{22}$
EPA 3		2	4	3	±2	ND	$1/2^{22}$
EPA 4		2	4	3	±2	ND	$1/2^{22}$
θ_{BX}	Roll gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.520 E-6	rad	$1/2^{31}$
θ_{BY}	Pitch gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.520 E-6	rad	$1/2^{31}$
θ_{BZ}	Yaw gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.520 E-6	rad	$1/2^{31}$
TF	Flight software time	11	4	6	2.748E11	msec	1/16
MODE	ACS mode. Earth pointing = 4	8	1	1	4	N/A	1
ICAL	ACS Reference. Earth sensor = 2, Inertial reference = 3	8	1	1	3	N/A	1
	Gyro rate mode. Low = 1, High = 0 (Bits 8,7,9)	9	1	1	1	N/A	1
CNGX	X-axis uncompensated gyro data	12	32	2	±1.633 E4	Counts	1/2*
CNGY	Y-axis uncompensated gyro data	12	32	2	±1.633 E4	Counts	1/2*
CNGZ	Z-axis uncompensated gyro data	12	32	2	±1.633 E4	Counts	1/2*
FLTROFF	CNGX, CNGY, CNGZ filter ON = 1, OFF = 0	8	1	1	1	N/A	1

*Low rate mode: 1 count = 1/20 arc second

ND = NONDIMENSIONAL

TF FORMAT

S	2^{37} ← MILLISECONDS OF YEAR → 2^{0}	2^{3} ← 1/16 msec → 2^{0}	X ← → X
47	46 ← → 9	8 ← → 5	4 ← → 0
TF	TF	TF	UNUSED

Note: EPA1, EPA2, EPA3, EPA4, θ_{BX}, θ_{BY}, θ_{BZ} appear in PCD also, but are sampled at different times and are scaled differently in PCD (as defined in 5.4.7.2).

Table 22
Ephemeris Computation Telemetry Report 1

Symbol	Definition	OBC Report	Samples per Major Frame	Number of Bytes	Range	Units	LSB Weight
EOGBRF(1)	Earth centered inertial (ECI) x-axis component of flight segment (FS) position computed using predicted-fit ephemeris	13	4	4	±8.3886E6	meters	$1/2^8$
EOGBRF(2)	ECI Y-axis component of FS position computed using predicted-fit ephemeris	13	4	4	±8.3886E6	meters	$1/2^8$
EOGBRF(3)	ECI Z-axis component of FS position computed using predicted-fit ephemeris	13	4	4	±8.3886E6	meters	$1/2^8$
EOGBVF(1)	ECI X-axis component of FS velocity computed using predicated-fit ephemeris	13	4	4	±8	meters/millisecond	$1/2^{28}$
EOGBVF(2)	ECI Y-axis component of FS velocity computed using predicated-fit ephemeris	13	4	4	±8	meters/millisecond	$1/2^{28}$
EOGBVF(3)	ECI Z-axis component of FS velocity computed using predicated-fit ephemeris	13	4	4	±8	meters/millisecond	$1/2^{28}$

9. LANDSAT-4 COMMUNICATIONS

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9.1 LANDSAT-4 X-BAND CHARACTERISTICS

The following information describes the Landsat-4 X-band link characteristics:

a. Frequency: 8.2125 GHz

b. Transmitter power: 44 watts

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (plus 7 dB)
- Gain at nadir (minus 9 dB)
- Spacecraft connection loss: 0.6 dB

d. Modulation scheme

- Unbalanced quadrature phase-shift keyed (UQPSK)
- MSS (15.0626 Mbps) data on the Q-channel
- TM (84.903 Mbps) data on the I-channel

e. Downlink spectrum: The TM data are PN-encoded on the spacecraft. Data are spread over approximately 170-MHz bandwidth.

9.1.1 Working Mode, Modulation, and Spectral Occupation

The Landsat-4 X-band transmit link uses a UQPSK modulation format for transmitting TM and MSS data. The TM data are usually modulated on the "I" carrier channel, and the MSS data on the "Q" carrier channel with a 4 to 1 power split. There will be three operational modes that are as follows:

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Mode	I-Channel	Q-Channel	Modulation
1	PN (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK
2	TM (84.903 Mbps)	TM (84.903 Mbps)	BPSK
3	TM (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK

The TM data are replaced with PN code for mode 1, in which only the MSS is operating. When only the TM is operating, the MSS data may be replaced with TM data. The TM data are PN-encoded within the instrument electronics. The MSS and TM are differentially encoded by converting from NRZ-L to NRZ-M for downlink transmission.

9.1.2 Output Filter Characteristics

A low-pass filter at the output of the TWT is planned to attenuate the TWTA second harmonic as well as the output noise to a level at which it will not degrade the Ku-band forward link receiver noise figure. A pre-TWTA four-pole 0.01-dB ripple Tschebyscheff filter with a matched bandwidth of 225 MHz is provided to meet power flux density restrictions. The X-band low-pass filter characteristics are as follows:

- Bandwidth: ±84 MHz
- Insertion loss: ≤ 0.15 dB
- VSWR: 1.15:1
- Phase deviation from linearity: ≤ 0.25 deg over ±84 MHz
- Insertion loss variation: ≤ 0.05 dB over ±84 MHz
- Gain slope: ≤ 0.01 dB/MHz over ±84 MHz
- Rejection: ≥ 31 dB at 16.4 GHz; ≥ 14 dB at 13.775 GHz

9.2 LANDSAT-4 S-BAND IMAGE DATA TRANSMISSION CHARACTERISTICS

The following information describes the Landsat-4 S-band image data transmission characteristics:

a. Carrier frequency: 2265.5 MHz

b. Transmitter power: 10 watts

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (+2.5 dB)
- Gain at nadir (-8 dB)
- Spacecraft connection loss: 1.5 dB

d. Modulation scheme

- NRZ-L PCM/FM
- MSS 15.0626 Mbps (same as Landsats-1 through -3)
- Deviation ±5.6 MHz ±5 percent

e. Downlink spectrum: MSS data are spread over approximately 20-MHz bandwidth.

9.3 LANDSAT-4 S-BAND TELEMETRY DATA TRANSMISSION CHARACTERISTICS

The S-band telemetry will be commanded on in response to a foreign station's request for telemetry data to support their MSS image data reception by either S-band or X-band. The following information describes the Landsat-4 S-band telemetry data transmission characteristics:

a. Frequency: 2287.5 Mhz

b. Effective isotropic radiation power: +3.2 dBW

c. Modulation scheme: 8 kbps

- PCM/PSK/PM
- 8-kbps data on 1.024-MHz subcarrier

- Carrier modulation index: 0.8 rad

d. Modulation scheme: 32-kbps PCD

- PCM/PM
- 32-kbps PM on carrier
- Carrier modulation index: 1.0 rad
- Frequency stability and aging temperature stability

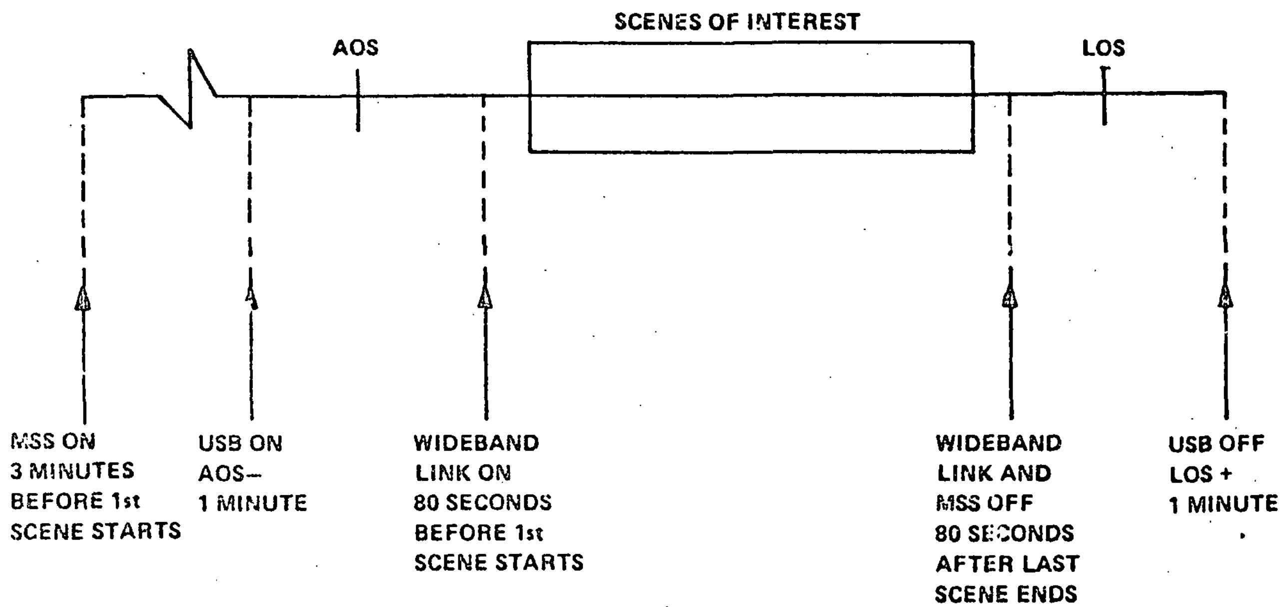
  - Combined effects over 1 year: ± 3.8 parts per 10^6

  - Short-term stability: the rms fractional deviation for a 3-minute period, measured with a 1.0-second integration time shall not exceed 3×10^{-9}.

e. Downlink spectrum: Data are spread over approximately 3-MHz bandwidth.

9.4 LANDSAT-4 X-BAND AND S-BAND COMMUNICATIONS TO FOREIGN GROUND STATIONS

Foreign ground stations can acquire TM video data by the X-band link only. PCD can be acquired by the X-band (in TM video). S-band (32-kbps data link) transmission of PCD to foreign ground stations is not planned. MSS video data can be acquired by the X-band link in addition to the S-band link, as is currently the case with Landsat-2 and Landsat-3. MSS telemetry data can be acquired on the S-band 8-kbps link. If required, S-band and X-band communications links can be operated simultaneously to satisfy foreign ground station coverage requirements for common areas. Simultaneous S-band and X-band image data transmission to one station will not be supported. The Landsat-4 Flight Segment has been designed to transmit a cumulative total of 100 daytime and 50 night thematic mapper scenes to participating user ground stations. A typical station pass transmission schedule is shown in Figure 29.



1 AOS AND LOS = 0° ELEVATION FROM STATION LOCATION

2 PBM GIVES: AOS AND LOS AS USB ON AND OFF TIMES
START OF 1st SCENE AS WIDEBAND ON TIME
END OF LAST SCENE AS WIDEBAND OFF TIME

Figure 29. Typical Ground Station Pass

Preliminary downlink carrier frequency stability for the X-band, S-band telemetry, and S-band image data communications links to foreign ground stations are as follows:

a. Landsat-4 S-band telemetry data transmission frequency stability: ±0.0004 percent inclusive of initial frequency setting, aging, and temperature stability effects over 1 year

b. Landsat-4 X-band transmission initial setting accuracy: 82125 GHz ±0.005 percent; frequency stability: ±0.0004 percent after 3 years in space

c. Landsat S-band image data transmission: ±0.0005 percent inclusive of initial frequency setting, aging, and temperature effects after 3 years in space

10. CHANNEL AND PROCEDURES FOR PROVIDING CALIBRATION DATA TO FOREIGN STATIONS

NASA/GSFC supplies calibration data to members of the Landsat Ground Station Operations Working Group (LGSOWG) only as authorized by NASA Headquarters. The following calibration data have been provided in the past to approved LGSOWG members:

a. Prelaunch mirror velocity profile
b. Postlaunch mirror velocity profiles as available
c. Prelaunch detector response curves

11. TELEMETRY TIME SIGNALS--ONBOARD CLOCK RESETTING PROCEDURE

The time of the onboard clock shall be accurate to ±20 milliseconds relative to Universal Time Coordinated (UTC). A daily update is expected to be adequate for maintaining this clock accuracy. Time updates will not be performed during MSS or TM data acquisitions. The daily update procedure is very brief and

will be scheduled so as to not interfere with or preclude the acquisition of any desired data.

At the change of the calendar year. a clock reset operation will be performed (in order to recycle the day of year counter). This reset operation will require a period of up to eight hours. in which normal MSS and TM operations will be suspended. The reset period will normally be scheduled to begin several hours before midnight GMT on December 31. Foreign ground stations will be advised of the schedule for this operation via Telex message. Any special requirements for coverage during the reset operation period should be submitted well in advance of December 31 to allow adequate time for planning.

APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT

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APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT

A1. GENERAL DESCRIPTION

A1.1 MULTISPECTRAL SCANNER FORMAT

The Multispectral Scanner (MSS) format described in the following paragraphs defines the serial bit stream following bit synchronization (i.e., input to high-density tape recorders). The MSS is capable of operating in two basic modes: compression and noncompression (linear), and may be operated at different gains as shown in Table A-1. The data format does not vary depending on the mode.

A2. BIT SYNCHRONIZATION OUTPUT FORMAT

The serial data stream can be observed after bit synchronization on the ground before any further processing. Thus, it agrees with the MSS MUX output on the Landsat-4 spacecraft. The data, after being encoded by the MUX, are in the format shown in Figure A-1. This format, which defines the details of one major frame of data containing 184,320 6-bit words, corresponds to one scan of the MSS scan mirror. Figure A-1 also shows a typical minor frame, 150 words output serially during the sensor data interval, that contains the 6- by 25-word matrix. The data rate is approximately 15.06 Mbps, which agrees with a data-word rate of approximately 2.5 by 10^6 words per second. The five segments of the

Table A-1
MSS Modes

Modes	Linear	Compressed	Gains 1X	Gains 3X
Band 1	X	X	X	X
Band 2	X	X	X	X
Band 3	X	X	X	
Band 4	X		X	

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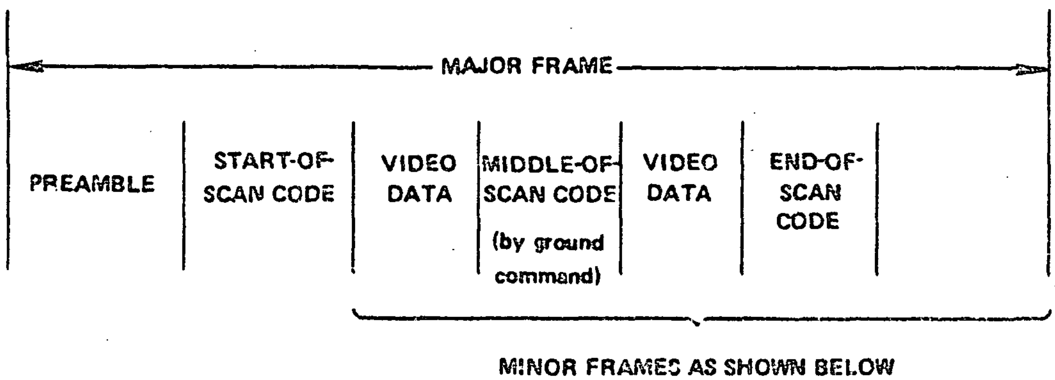

ROW = 25 WORDS

ROW 1	MNFS	SENSOR 1 (1A)	SENSOR 2 (2A)	· · · · · ·	SENSOR 24 (4F)	MINOR FRAME 150 WORDS
ROW 2	(BLANK)	SENSOR 1	SENSOR 2	· · · · · ·	SENSOR 24	
ROW 3	(BLANK)	SENSOR 1	SENSOR 2	· · · · · ·	SENSOR 24	
ROW 4	MNFS	SENSOR 1	SENSOR 2	· · · · · ·	SENSOR 24	
ROW 5	(BLANK)	SENSOR 1	SENSOR 2	· · · · · ·	SENSOR 24	
ROW 6	(BLANK)	SENSOR 1	SENSOR 2		SENSOR 24	

MNFS = MINOR FRAME SYNC CODE

Note: The sampling sequence shall be 1A, 2A, 1B, 2B,...3F, 4F.

Following the start-of-scan code rows 1 and 2 of the first minor frame contain 49 words of time-code data in place of sensor data.

Figure A-1. Multiplexer Output Data Format

major-frame format plus the calibration data format are discussed in the following subsections. Figure A-2 and Table A-2 are provided as reference for timing, coding, and other specifics.

A2.1 PREAMBLE

The start of the preamble defines the start of the major frame. The pattern is 000111 repeated at the data word rate. The preamble is terminated at the end of the word period during which the start of scan monitor pulse is received from the scanner.

A2.2 START-OF-SCAN CODE

The single word following the termination of the preamble is the start of the scan (SMC-1) code pattern, 111000, which appears in the data stream immediately after a preamble word. Thus, an indication of the line start (i.e., beginning of active scan) is the appearance of six adjacent ones.

A2.3 VIDEO DATA

Following the start-of-scan code, the MSS MUX begins to transmit data that are grouped in minor frames of 150 words (i.e., six rows of 25 words each) as shown in Figure A-1. The minor-frame synchronization (MNFS) code is 001011 and occurs as the first word in row 1. The complement of the MNFS occurs as the first word in row 4 of each minor frame. The time-code data from the spacecraft clock are inserted in word positions 2 through 49 of rows 1 and 2 of the first minor frame of each scan in place of sensor data as shown in Figures A-3 and A-4. Figure A-4 shows the placement of various units of the BCD time code in different scans. The total code requires that two scans be inserted, and the format alternates back and forth every two scans. Figure A-3 relates the time-code clock output to the MUX-generated envelope and the time-code input to the MUX and shows their relationship

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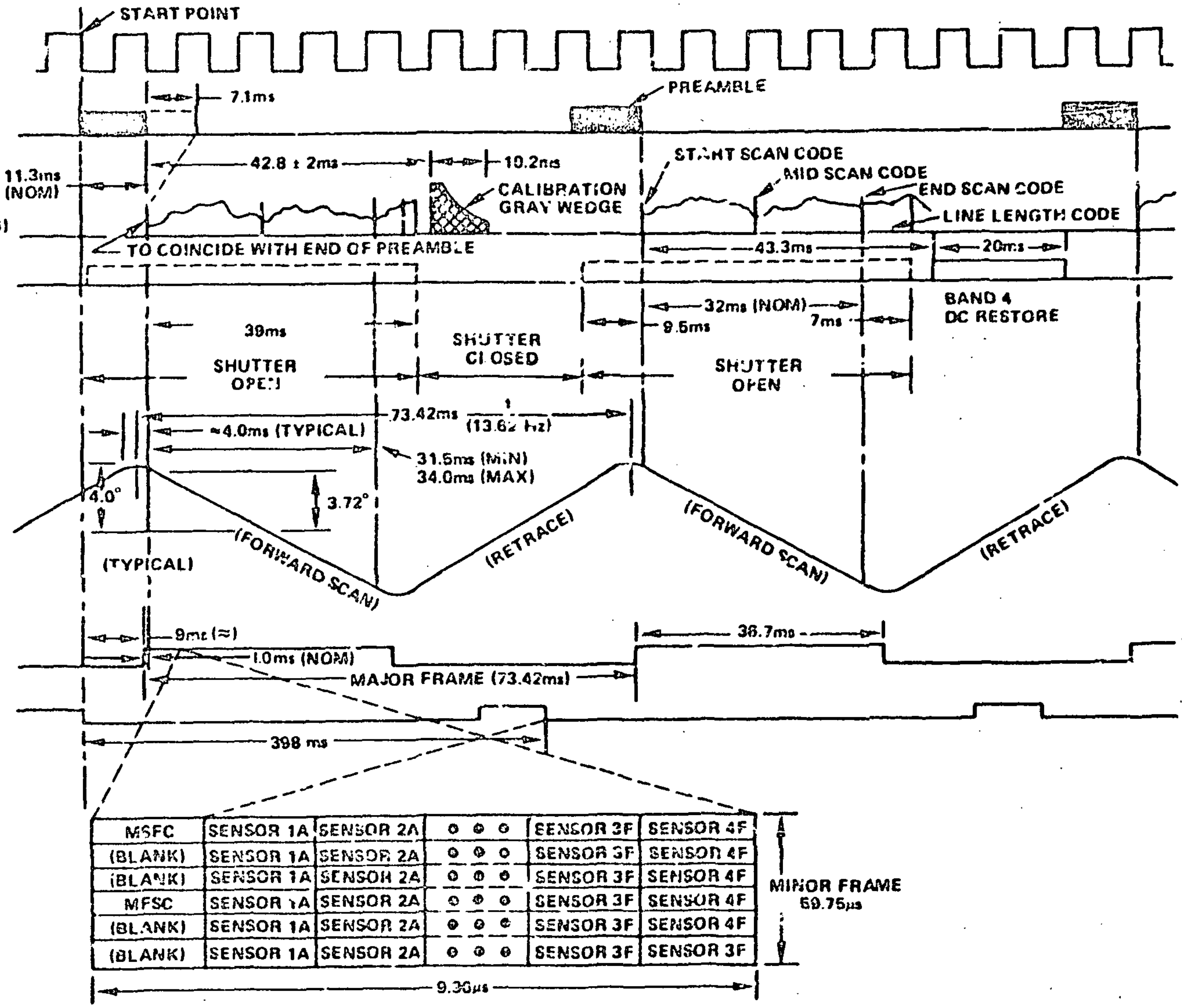


Figure ˙ 4. Multiplexer Data Timing and Format

Table A-2
Multispectral Scanner Multiplexer and Bit Sync Format

	Coding (6-bit word)	Nominal Time Duration	Nominal Number of Words
Preamble	000111	11.3 ms $\pm$3 ms	28762 $\pm$7503
Start-of-scan code (SMC-1)	111000	0 398 μs	1
Minor-frame sync (MNFS)	001011	0.398 μs	1
Time code	Logic 1's and 0's (110011 and 001100)	.522 μs	49
Sensor data (video)	Data**	32 ms total	82533
Middle-of-scan code (SMC-M)	100 black* 100 white	79.682 μs	200
End-of-scan code (SMC-2)	100 black* 100 white	79.682 μs	200
Calibration wedge	Data**	10.2 ms	25510
Preamble	Data**	8.871 ms	22186

*Black 001100, white 110011
**Binary: 0 to 63 levels with center two bits inverted (e.g., level 6 = 001010).

within the first minor frame of each scan. Although the spacecraft clock provides a 49-bit NRZ-L time code to the MUX, the 49th bit of the code is not accepted by the MUX. Note the time-code envelope in Figure A-3. Also note that spacecraft clock bit 25 is a dummy bit. As for sensor data, a time-code data zero bit is encoded by the MUX as output data bits 001100, and a time-code data one bit as 1100011.

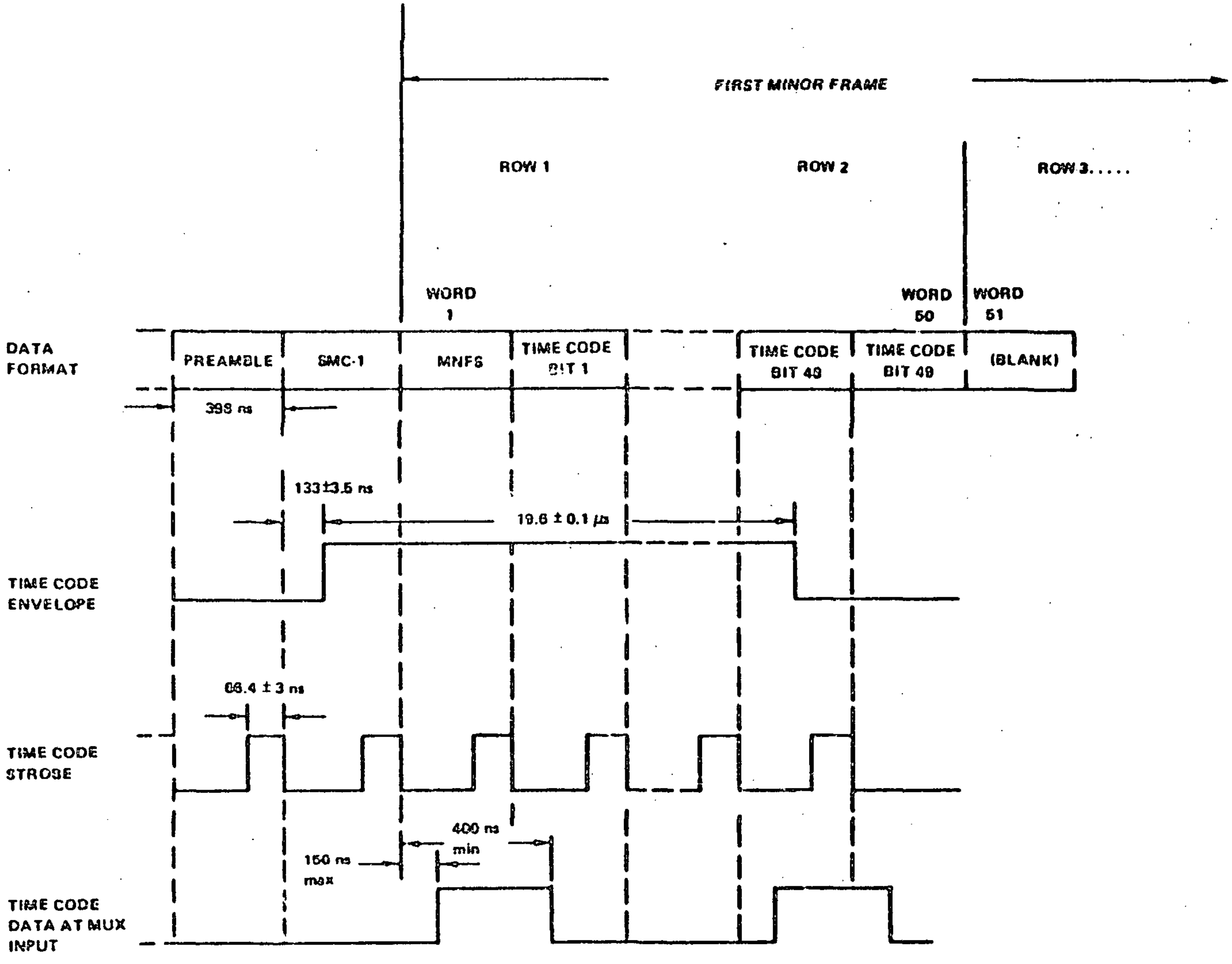
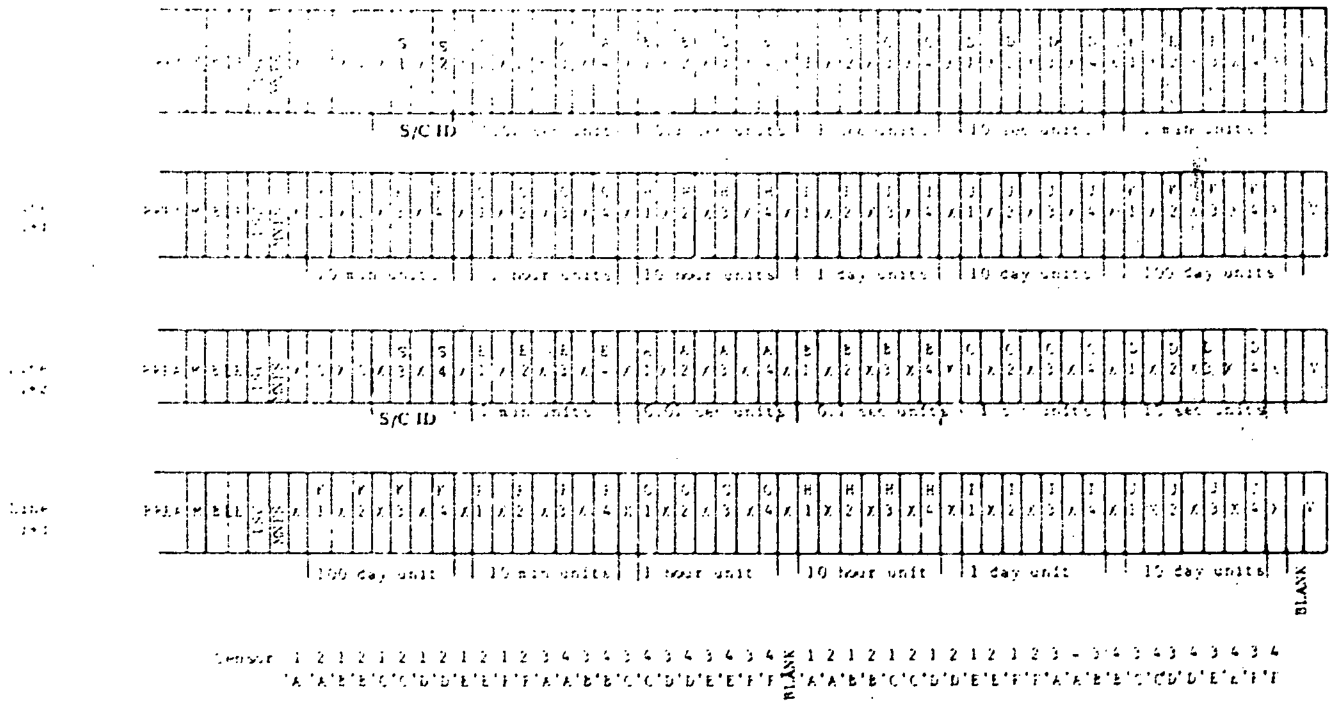


Figure A-3. Relationship of Time Code Signals to Multiplexer Output



Time-code
update every
1+2n lines
where n = 1,2,3...

Notes:
1. LSB first in time
2. Coding

	0	1
Mux. Internal	000000	111111
Mux. output	001100	110011

3. No data during time code – x
4. Video data – V
5. Line start code – LSC
6. XXXX – spaces
7. S1-S4 = spacecraft ID as follows:
   1110 = Landsat-D
   1101 = Landsat-D'

Notation

A = hundreths of seconds
B = tenths of seconds
C = units seconds
D = tens seconds
E = units minutes
F = tens minutes
G = units hours
H = tens hours
I = units days
J = tens days
K = hundreds days

Figure A-4. MSS Time Code Format for Landsat-4

Word positions 2 through 25 in all other rows contain encoded sensor data words from Bands 1 through 4. The signal from each band is converted to a binary code in which 000000 represents the least positive voltage levels. After conversion to their binary equivalent, the data are encoded in the MUX by inverting data bits 3 and 4 in each sensor data word (i.e., binary level 0000000 will be encoded as 001100). Sensor data are transmitted with the MSB first.

A2.4 MIDDLE-OF-SCAN CODE

When operated in the midscan indicator ON mode, the MUX preempts transmission of sensor data on receipt of the middle-of-scan monitor pulse from the scanner and transmits the middle-of-scan code. Beginning with the word period immediately following the receipt of the pulse, the MUX transmits the encoded equivalent of the black-sensor level (i.e., 0.00 volt input, code 001100) for the next 100-word periods. In the subsequent 100-word periods, the encoded equivalent of the white-sensor level (i.e., 4.0 volts input, code 110011) is transmitted. In the next word period, sensor data resume. (Note that only sensor data are preempted; minor frame synchronization codes are inserted in their proper locations but are included in the count of word periods.) When operated in the midscan indicator OFF mode, the MUX ignores the middle-of-scan monitor pulse and continues to transmit sensor data from the scanner. NASA plans to use the midscan code to develop and/or validate mirror velocity profiles and mirror scan repeatability. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements.

A2.5 END-OF-SCAN CODE

On receipt of the end-of-scan monitor pulse from the scanner, the MUX preempts transmission of sensor data from the scanner and transmits the end-of-scan code. This code is identical to the

black-and-white level code patterns of the middle-of-scan code. After transmission of end-of-scan code (200-word periods), sensor data resume until the end of the major frame.

A2.6 INTERNAL CALIBRATION DATA

Whereas the preceding five subsections cover MUX data output patterns, internal calibration differs in that the MUX does not control it. Calibration data appear in the serial data stream during every other retrace interval (i.e., between the end-of-scan code and the beginning of preamble). During the retrace interval, the scan mirror makes the transmit from east to west, a shutter wheel closes off the optical fiber view to the Earth, and a light source (calibration lamp) is projected onto the fibers through a variable neutral-density filter on the shutter wheel. This process introduces a calibration wedge into the video data stream of Bands 1 through 4 during this retrace interval. The nominal shape of the calibration or gray wedge is shown in Figure A-5. The actual shape and level varies somewhat for the detectors in the various spectral bands. The calibration wedge is about 10.2 ms in total duration wedge density levels (digital) decrease from 63 to 0 and the wedge appears once every 147 ms. Assuming that the calibration lamp intensity is constant, it is possible to obtain a check of the relative radiometric levels and to equalize gain changes that may occur in the six detectors of a spectral band.

Since internal calibration is a function of the rotating shutter and calibration lamp and is not controlled by the MUX, it does not occur at the exact word position in the data stream of every other scan retrace. The purpose of the calibration wedge is to determine that the calibration lamp, neutral-density wedge, optics train, and radiometer visual channels are providing a calibration lamp versus time that can be processed to provide the required number of gray-scale levels of descending half-power

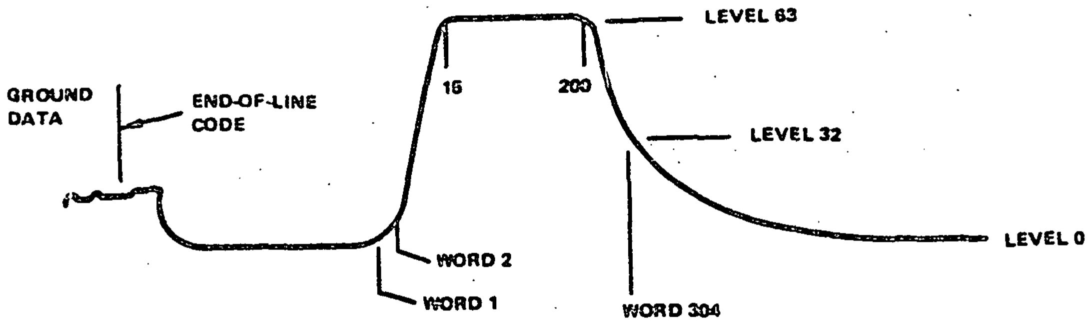


Figure A-5. Nominal Calibration Wedge Curve

levels. Thus, during every other scan retrace, about 10 ms of minor frames contain calibration data in the sensor data words; beginning about 11 ms after end-of-line (noncalibration retraces), the sensors output a black level derived from the detectors looking at a dark surface on the shutter. As with all other sensor data words, the internal calibration data are encoded by inverting the middle two bits. Figure A-6 shows details within the scanner related to internal calibration and Band 4 dc restoration.

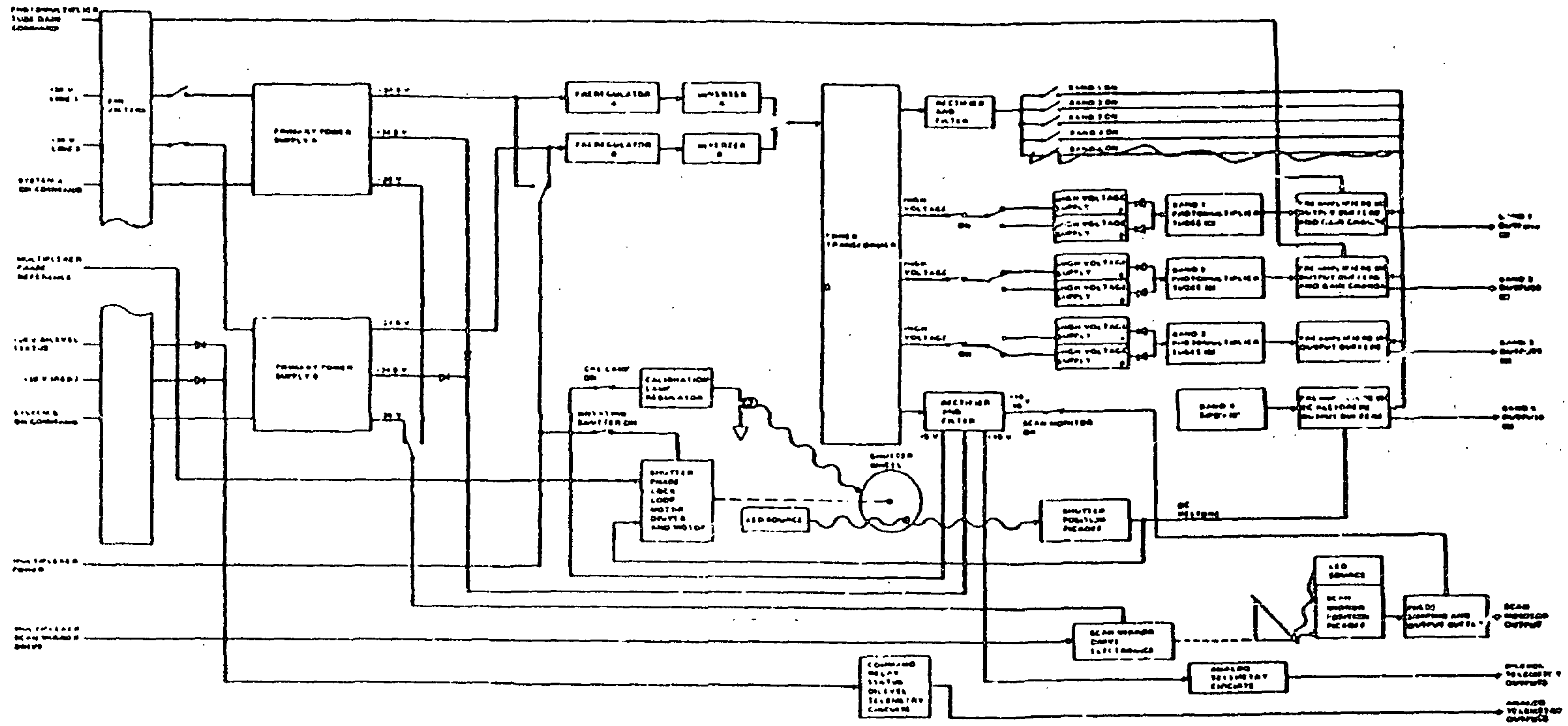


Figure A-6. Scanner Functional Block Diagram

APPENDIX B

MSS DATA PROCESSING CONSTANTS

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APPENDIX B
MSS DATA PROCESSING CONSTANTS

B1. SPACECRAFT AND SENSOR CONSTANTS

Table B-1 lists the values for certain spacecraft and sensor constants required in ground processing. The MSS band-to-band offsets are given for Bands 2, 3 and 4 with an implied zero for Band 1. The offset is a number such that when added to a "sampling time delay" for a detector of that band, the result is an offset in pixels for that detector from a fictitious detector for which the resampling matrices were formed. Thus 27 numbers are given: 3 "band-to-band" offsets and 24 "sampling time" delays. (A set of six is repeated for each band.) This particular partition was selected to satisfy certain historically acceptable formats. Decompression data are provided in Table B-2.

Table B-1
Spacecraft and Sensor Constants

Data Description	Values
Nominal number of pixels per input line	3240
Nominal scale of input interpixel distance in meters per pixel	57
Nominal scale of input interline distance in meters per pixel	82.7
Nominal spacecraft altitude in meters	705300
Nominal input swath width in meters	185000
The prelaunch mirror scan profile for MSS is of the following form:	
$\ell = 2 \cdot A \cdot e^{-\beta (i - 1) t_s} \cdot \sin W (t_0 + \{i - 1\} t_s)$	
with	
ℓ = scan angle, rad.	

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Table B-1
Spacecraft and Sensor Constants (Continued)

Data Description	Values
A = harmonic amplitude	0.23387 rad
β = damping constant	0.00739/sec
i = pixel number	$1 \le i \le$ linelength
t_s = sampling time	9.958 μsec
W = mirror frequency	17.499 rad/sec
t_0 = start time for scan relative to center pixel time	-16.15 ms
MSS maximum mirror angle in radians	0.25996
Time between successive MSS mirror sweeps in seconds	0.07342
Time for the active portion of an MSS mirror sweep in seconds	0.03230
MSS sampling delay consists of 24 values, (one for each detector) measured in input image along-scan pixel units. The MSS sampling delay constants will appear in the following order:	
Band 1 Detector 1	-2.720805
Detector 2	-2.800665
Detector 3	-2.880525
Detector 4	-2.960385
Detector 5	-3.040245
Detector 6	-3.120105
Band 2 Detectors 1-6 Band 3 Detectors 1-6 Band 4 Detectors 1-6 — Same values as for Band 1 Detectors 1-6, respectively	
MSS band-to-band offsets with respect to Band 1 (3 values: one each for Bands 2, 3 and 4) measured in input image along-scan pixel units	Band 2 = 1.95007 Band 3 = 3.89084 Band 4 = 5.84091

Table B-2
Landsat-D MSS Decompression Table

Compressed Quantum Level	Equivalent Linear Quantum Level		Compressed Quantum Level	Equivalent Linear Quantum Level	
	Bands 1&3	Band 2		Bands 1&3	Band 2
0	0	0	32	42	42
1	1	1	33	44	44
2	2	2	34	46	46
3	3	2	35	48	48
4	3	3	36	50	49
5	4	4	37	52	51
6	5	5	38	54	54
7	6	6	39	56	56
8	7	7	40	59	59
9	8	8	41	62	61
10	9	9	42	65	64
11	10	10	43	67	67
12	11	11	44	70	70
13	12	12	45	73	73
14	13	13	46	76	76
15	14	14	47	79	79
16	16	16	48	82	81
17	17	17	49	85	84
18	18	18	50	88	87
19	20	19	51	91	90
20	21	21	52	94	93
21	22	22	53	96	96
22	24	24	54	99	99
23	26	26	55	102	102
24	27	27	56	105	105
25	29	29	57	108	108
26	31	31	58	111	111
27	33	33	59	114	114
28	34	34	60	117	117
29	36	36	61	120	120
30	38	38	62	123	123

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B2. CALIBRATION WEDGE WORD COUNT VALUES

Table B-3 presents the number of pixels from the midpoint of the calibration wedge leading edge to the point at which each of six values are to be extracted for use in gain and offset calculations. Separate table segments are provided for each mode of sensor operation (high gain/low gain, use of prime/redundant calibration source lamp). Within each segment, sets of six word count values are provided for each band; and each set applies to all detectors within the band.

Table B-3
Calibration Wedge Word Count Values

	Calibration Wedge Word Count* For Locating Sample Number:					
• Lamp A (Prime)						
High Gain:	1	2	3	4	5	6
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
• Lamp B (Redundant)						
High Gain:						
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760

Table B-3
Calibration Wedge Word Count Values (Continued)

Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760

*Number of pixels (words), counting from the first pixel of the leading edge of the cal. wedge which has a value ≥ 32, to the location of each of the six word samples to be extracted from the wedge.

B3. NOMINAL CALIBRATION QUANTUM LEVEL VALUES

Table B-4 presents the nominal digital values that can be expected at each calibration wedge location defined in Table B-3. Separate table segments are provided for each combination of sensor mode (high/low gain, use of prime/redundant calibration source lamp) and signal amplifier mode (linear/compressed). Within each segment, radiance values are provided for each word count value of each detector.

B4. OFFSET AND GAIN COEFFICIENTS (C_i and D_i Values)

Tables B-5, B-6, B-7 and B-8 present the regression coefficients used with calibration wedge radiance values (which are extracted at locations defined by Table B-3) to calculate the gain and offset values that describe the radiance calibration function for each detector. Each table describes a mode of sensor operation (high/low gain, use of prime/redundant calibration source lamp). Within each table, separate segments are provided for detector of each band. Each segment contains an offset coefficient value and a gain coefficient value for each of the six calibration quantum level values to be extracted from the calibration wedge portion of the MSS data.

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Table B-4
Nominal Calibration Record

1st Detector of Band						2nd Detector of Band						3rd Detector of Band						4th Detector of Band						5th Detector of Band						6th Detector of Band						
1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	
ACTIVE DETECTOR STATUS AAAAAAAAAAAAAAAAAAAAAAAA																																				
CAL WEDGE (HIGH GAIN, LINEAR, LAMP A)																																				
44	42	40	38	2	2	45	42	40	38	2	2	46	44	42	40	2	2	45	42	41	43	2	2	44	42	40	38	[illegible]	2	46	44	41	40	2	2	Band 1
42	40	38	34	2	1	45	42	40	37	2	1	39	36	33	31	[illegible]	1	40	37	36	33	2	1	41	39	35	34	2	1	42	39	37	35	2	1	Band 2
46	43	40	38	3	3	48	43	41	39	3	3	47	45	43	40	3	3	46	42	40	39	3	3	45	41	40	38	3	2	46	43	41	38	3	2	Band 3
52	48	48	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	45	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP A)																																				
50	47	45	43	2	2	50	47	45	43	2	2	52	49	47	44	2	2	51	48	46	43	2	2	49	48	44	42	2	2	50	48	45	43	2	2	Band 1
50	47	44	42	2	2	54	50	48	45	2	2	48	43	41	39	2	2	48	45	42	40	2	2	50	47	45	42	2	2	51	48	46	43	2	2	Band 2
45	43	40	38	3	3	48	43	41	39	3	3	47	45	43	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	48	[illegible]		38	3	2	Band 3
52	48	48	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	48	43	40	38	[illegible]	4	Band 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP A)																																				
47	46	44	43	4	3	48	48	45	44	5	4	49	49	48	46	5	4	49	48	48	46	5	4	43	42	41	40	5	3	47	48	44	43	5	3	Band 1
48	44	42	41	5	3	50	47	46	44	5	4	45	44	42	40	5	3	46	44	42	41	5	3	48	46	44	43	5	4	48	46	44	42	5	[illegible]	Band 2
55	53	51	49	7	6	55	53	51	49	7	6	57	54	52	51	7	6	54	52	51	49	7	7	54	52	51	49	8	6	54	52	51	49	7	6	Band 3
54	51	48	45	5	5	53	49	45	44	5	5	55	51	48	45	5	5	52	48	48	42	5	5	47	44	41	38	4	4	48	45	42	40	4	4	Band 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP A)																																				
52	50	48	47	5	4	51	49	48	46	4	4	54	51	50	48	5	5	52	51	50	48	5	4	46	45	43	42	3	4	50	48	47	45	4	4	Band 1
51	49	47	46	5	4	55	53	51	49	5	5	51	48	48	46	5	5	51	49	47	46	5	5	53	51	50	48	5	[illegible]	54	52	50	49	5	5	Band 2
55	53	51	49	7	6	56	53	51	49	7	6	57	54	52	51	7	6	54	52	51	49	7	7	54	52	51	49	8	6	54	52	51	49	7	6	Band 3
54	51	48	45	5	5	53	49	46	44	5	5	55	51	48	45	5	5	52	48	48	42	5	5	47	44	41	38	4	4	48	47	42	40	4	4	Band 4
CAL WEDGE (HIGH GAIN, LINEAR, LAMP B)																																				
46	43	41	39	3	2	46	43	41	39	3	2	47	45	43	41	3	2	45	44	42	39	3	2	45	[illegible]	41	39	3	2	47	44	42	40	3	2	Band 1
44	41	40	38	4	4	47	44	42	40	4	4	39	37	36	34	4	3	42	40	38	36	4	4	44	42	40	38	4	4	46	43	41	39	4	4	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	39	[illegible]	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP B)																																				
51	48	46	44	2	2	51	48	46	43	2	2	53	50	47	45	2	2	52	49	47	45	2	2	50	48	46	43	2	2	52	49	47	45	2	2	Band 1
50	47	45	42	2	2	52	51	48	45	3	2	46	43	41	39	2	2	48	46	43	40	2	2	51	49	46	43	3	2	53	50	47	45	3	2	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	38	3	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	[illegible]	3	Band 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP B)																																				
51	50	48	47	6	6	51	50	48	47	7	6	53	51	50	48	7	6	52	50	48	47	7	6	51	50	48	47	6	6	52	51	49	47	7	6	Band 1
51	49	47	46	9	9	52	51	49	48	9	9	47	49	46	43	9	8	49	48	46	45	9	9	51	49	48	46	10	9	52	50	48	47	10	9	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	[illegible]	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP B)																																				
55	53	52	50	5	5	56	53	51	50	5	5	57	55	53	51	6	2	56	54	52	51	6	2	55	53	51	50	5	5	56	54	52	51	[illegible]	6	Band 1
55	53	51	49	5	5	57	55	53	51	6	5	52	50	49	47	6	5	53	52	50	49	6	5	55	54	52	50	7	6	56	55	53	51	7	6	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4

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Table B-5
Lamp A (Prime) - High Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5034660E-01	-0.2014560E-01	0.9569900E-02	0.3634670E-01	0.5090237	0.5155502	Band 1
	GAINS:	0.4393935	0.3782430	0.3180776	0.2638616	-0.6931777	-0.7063921	
DETECTOR 2	OFFSETS:	-0.4696410E-01	-0.1757830E-01	0.1402540E-01	0.3933630E-01	0.5018356	0.5093431	
	GAINS:	0.4459089	0.3845716	0.3186063	0.2657740	-0.6995937	-0.7152642	
DETECTOR 3	OFFSETS:	-0.4951040E-01	-0.2031000E-01	0.9761000E-02	0.3898490E-01	0.5069316	0.5141420	
	GAINS:	0.4415793	0.3819324	0.3205073	0.2608126	-0.6950506	-0.7097797	
DETECTOR 4	OFFSETS:	-0.4863200E-01	-0.1637630E-01	0.1167500E-01	0.3624920E-01	0.5049975	0.5120457	
	GAINS:	0.4504787	0.3671738	0.3242962	0.2686936	-0.7079045	-0.7227359	
DETECTOR 5	OFFSETS:	-0.4772620E-01	-0.1728000E-01	0.1305600E-01	0.3843460E-01	0.5031191	0.5103938	
	GAINS:	0.4419056	0.3791494	0.3166170	0.2643114	-0.6934960	-0.7066066	
DETECTOR 6	OFFSETS:	-0.4818700E-01	-0.1804520E-01	0.1234110E-01	0.3968050E-01	0.5031267	0.5110831	
	GAINS:	0.4475009	0.3847212	0.3214320	0.2644894	-0.7007845	-0.7173566	
DETECTOR 7	OFFSETS:	-0.4978410E-01	-0.1379920E-01	0.2319780E-01	0.5015760E-01	0.4914715	0.4987552	Band 2
	GAINS:	0.4471573	0.3728172	0.2963865	0.2406913	-0.6710020	-0.6860487	
DETECTOR 8	OFFSETS:	-0.4786690E-01	-0.5499200E-02	0.2722290E-01	0.4969290E-01	0.4850060	0.4914417	
	GAINS:	0.4527151	0.3633089	0.2942579	0.2468412	-0.6717733	-0.6853501	
DETECTOR 9	OFFSETS:	-0.4764340E-01	-0.6085000E-02	0.3098510E-01	0.5721700E-01	0.4803672	0.4851587	
	GAINS:	0.4620484	0.3724492	0.2925267	0.2359710	-0.6763325	-0.6866624	
DETECTOR 10	OFFSETS:	-0.4595430E-01	-0.1156960E-01	0.2572820E-01	0.5119440E-01	0.4871623	0.4934390	
	GAINS:	0.4537220	0.3603466	0.3007549	0.2464136	-0.6839200	-0.6973141	
DETECTOR 11	OFFSETS:	-0.4826260E-01	-0.1290520E-01	0.2150040E-01	0.4753510E-01	0.4926770	0.4994534	
	GAINS:	0.4394034	0.3671185	0.2967794	0.2435538	-0.6664366	-0.6803529	
DETECTOR 12	OFFSETS:	-0.4813160E-01	-0.9664100E-02	0.2116110E-01	0.4747740E-01	0.4910113	0.4981651	
	GAINS:	0.4532148	0.3720921	0.3070097	0.2514836	-0.6844521	-0.6894466	
DETECTOR 13	OFFSETS:	-0.5704220E-01	-0.2197540E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	Band 3
	GAINS:	0.4055327	0.3419647	0.2866595	0.2303389	-0.6282750	-0.6368208	
DETECTOR 14	OFFSETS:	-0.5796830E-01	-0.2231510E-01	0.8275200E-02	0.3914950E-01	0.5141711	0.5186867	
	GAINS:	0.4074523	0.3427829	0.2872969	0.2312958	-0.6303163	-0.6385089	
DETECTOR 15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4115500E-02	0.3753270E-01	0.5200683	0.5246107	
	GAINS:	0.4143347	0.3552930	0.2981066	0.2366220	-0.6481126	-0.6566431	
DETECTOR 16	OFFSETS:	-0.6022840E-01	-0.2476510E-01	0.7526200E-02	0.3820340E-01	0.5173103	0.5218927	
	GAINS:	0.4272965	0.3605108	0.2996986	0.2418133	-0.6603647	-0.6689765	
DETECTOR 17	OFFSETS:	-0.5873130E-01	-0.2233320E-01	0.8034400E-02	0.3840870E-01	0.5149243	0.5196952	
	GAINS:	0.4306794	0.3611317	0.3031066	0.2450639	-0.6654352	-0.6745509	
DETECTOR 18	OFFSETS:	-0.5866450E-01	-0.2347670E-01	0.8840600E-02	0.3874310E-01	0.5149391	0.5196175	
	GAINS:	0.4225129	0.3565332	0.2959356	0.2392639	-0.6540377	-0.6618102	
DETECTOR 19	OFFSETS:	-0.8950200E-01	-0.4144660E-01	-0.3951700E-02	0.3990730E-01	0.5467716	0.5482212	Band 4
	GAINS:	0.4161379	0.3380703	0.2771646	0.2059174	-0.6174662	-0.6198230	
DETECTOR 20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881090E-01	0.5463896	0.5485971	
	GAINS:	0.4322807	0.3536371	0.2651537	0.2160676	-0.6417063	-0.6454350	
DETECTOR 21	OFFSETS:	-0.8683630E-01	-0.3995820E-01	-0.1126500E-02	0.3891670E-01	0.5437302	0.5452751	
	GAINS:	0.4122705	0.3417387	0.2775145	0.2112865	-0.6236263	-0.6261635	
DETECTOR 22	OFFSETS:	-0.8285550E-01	-0.4554920E-01	-0.2763300E-02	0.4066930E-01	0.5471393	0.5488122	
	GAINS:	0.4478498	0.3727766	0.2976214	0.2213647	-0.6683377	-0.6712764	
DETECTOR 23	OFFSETS:	-0.8513990E-01	-0.4288810E-01	-0.7428000E-03	0.3921280E-01	0.5441099	0.5455476	
	GAINS:	0.4754781	0.3958642	0.3161137	0.2406665	-0.7127149	-0.7154702	
DETECTOR 24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3246000E-03	0.3645530E-01	0.5442715	0.5461547	
	GAINS:	0.4599492	0.3832669	0.3061812	0.2387447	-0.6923453	-0.6957984	

Table B-6
Lamp A (Prime) - Low Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

			FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR	1	OFFSETS:	-0.5044050E-01	-0.2074100E-01	0.8467600E-02	0.3403190E-01	0.5137314	0.5149616	
		GAINS:	0.4066399	0.3510138	0.2983050	0.2484233	-0.6500483	-0.6523336	
DETECTOR	2	OFFSETS:	-0.4998130E-01	-0.1638700E-01	0.7744700E-02	0.3452640E-01	0.5123792	0.5130988	
		GAINS	0.4174407	0.3501867	0.3078817	0.2558161	-0.6692752	-0.6718299	
DETECTOR	3	OFFSETS:	-0.4889510E-01	-0.1809270E-01	0.7018700E-02	0.3240320E-01	0.5136559	0.5150127	
		GAINS:	0.4083168	0.3518636	0.3024074	0.2543204	-0.6570740	-0.6598334	
DETECTOR	4	OFFSETS:	-0.4896040E-01	-0.1841010E-01	0.7305400E-02	0.3300160E-01	0.5131428	0.5148601	Band 1
		GAINS:	0.4205461	0.3628122	0.3108079	0.2605746	-0.6757452	-0.6790944	
DETECTOR	5	OFFSETS:	-0.4955000E-01	-0.2222870E-01	0.9532700E-02	0.3481040E-01	0.5120960	0.5147414	
		GAINS:	0.4177801	0.3649877	0.3036176	0.2647766	-0.6686032	-0.6726672	
DETECTOR	6	OFFSETS:	-0.4073960E-01	-0.1688300E-01	0.7961100E-02	0.3240870E-01	0.5132293	0.5149465	
		GAINS:	0.4202262	0.3603068	0.3081800	0.2605552	-0.6729670	-0.6762997	
DETECTOR	7	OFFSETS:	-0.5544000E-01	-0.1940160E-01	0.1182860E-01	0.4251380E-01	0.5086271	0.5118808	
		GAINS:	0.3701566	0.3151097	0.2622208	0.2102547	-0.5791156	-0.5848258	
DETECTOR	8	OFFSETS:	-0.5443910E-01	-0.1916970E-01	0.1063320E-01	0.3807600E-01	0.5090676	0.5134306	
		GAINS:	0.3768380	0.3167271	0.2659329	0.2164330	-0.5849292	-0.5910016	
DETECTOR	9	OFFSETS:	-0.5335200E-01	-0.1817020E-01	0.1166940E-01	0.3858120E-01	0.5080645	0.5121167	
		GAINS:	0.3771513	0.3168435	0.2657101	0.2194242	-0.5860360	-0.5921633	Band 2
DETECTOR	10	OFFSETS:	-0.5441040E-01	-0.1823660E-01	0.1291340E-01	0.4082070E-01	0.5080326	0.5108856	
		GAINS:	0.3847621	0.3217964	0.2676844	0.2190160	-0.5940308	-0.5900620	
DETECTOR	11	OFFSETS:	-0.5380000E-01	-0.1977140E-01	0.1027140E-01	0.4085980E-01	0.5094633	0.5129768	
		GAINS:	0.3898081	0.3126268	0.2622498	-0.2109677	-0.5748162	-0.5807097	
DETECTOR	12	OFFSETS:	-0.5412680E-01	-0.1990290E-01	0.8928100E-02	0.4152150E-01	0.5094231	0.5131674	
		GAINS:	0.3807511	0.3217345	0.2702951	0.2150098	-0.5910753	-0.5975148	
DETECTOR	13	OFFSETS:	-0.5704220E-01	-0.2197640E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	
		GAINS:	0.4055327	0.3419647	0.2866696	0.2303389	-0.6282750	-0.6361200	
DETECTOR	14	OFFSETS:	-0.5780830E-01	-0.2231610E-01	0.8275200E-02	0.3914050E-01	0.5141711	0.5180887	
		GAINS:	0.4074523	0.3427829	0.2372969	0.2312958	-0.6303103	-0.6385039	
DETECTOR	15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4115500E-02	0.3753270E-01	0.5200083	0.5246107	
		GAINS:	0.4143347	0.3552930	0.2981063	0.2368220	-0.6481126	-0.6564431	Band 3
DETECTOR	16	OFFSETS:	-0.6022840E-01	-0.2476510E-01	0.7626200E-02	0.3026340E-01	0.5173103	0.5218927	
		GAINS:	0.4272896	0.3605190	0.2996986	0.2418133	-0.6603447	-0.6609745	
DETECTOR	17	OFFSETS:	-0.5873130E-01	-0.2233320E-01	0.8034400E-02	0.3840870E-01	0.5149243	0.5186952	
		GAINS:	0.4306794	0.3611317	0.3031066	0.2450689	-0.6654362	-0.6745509	
DETECTOR	18	OFFSETS:	-0.5866460E-01	-0.2347670E-01	0.8040600E-02	0.3874310E-01	0.5149381	0.5190175	
		GAINS:	0.4225129	0.3665332	0.2959358	0.2390064	-0.6530377	-0.6618102	
DETECTOR	19	OFFSETS:	-0.8950200E-01	-0.4144460E-01	-0.3951700E-02	0.3090730E-01	0.5487716	0.5482212	
		GAINS:	0.4161379	0.3380703	0.2771048	0.2050172	-0.5174682	-0.6168230	
DETECTOR	20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881080E-01	0.5483898	0.5486971	
		GAINS:	0.4322007	0.3535371	0.2851537	0.2160670	-0.6417043	-0.6464350	
DETECTOR	21	OFFSETS:	-0.8683530E-01	-0.3955820E-01	-0.1126500E-02	0.3891670E-01	0.5437302	0.5452751	
		GAINS:	0.4192705	0.3417387	0.2775146	0.2112865	-0.6236283	-0.6201835	
DETECTOR	22	OFFSETS:	-0.8828550E-01	-0.4654020E-01	-0.2753300E-02	0.4054930E-01	0.5471393	0.5408122	Band 4
		GAINS:	0.4478498	0.3727786	0.2978214	0.2213627	-0.6663377	-0.6712764	
DETECTOR	23	OFFSETS:	-0.8513990E-01	-0.4288810E-01	-0.7428000E-03	0.3021280E-01	0.5441099	0.5455478	
		GAINS:	0.4754781	0.3958842	0.3161137	0.2409566	-0.7127149	-0.7164302	
DETECTOR	24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3243000E-03	0.3646630E-01	0.5442715	0.5401647	
		GAINS:	0.4599492	0.3832860	0.3061812	0.2387447	-0.6923453	-0.6957984	

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Table B-7

Lamp B (Redundant) - High Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5383770E-01	-0.2314010E-01	0.6895000E-02	0.3447840E-01	0.5152770	0.5203240	
	GAINS:	0.4306146	0.3706659	0.3120100	0.2581455	-0.6607873	-0.6906456	
DETECTOR 2	OFFSETS:	-0.5131310E-01	-0.2134540E-01	0.8583100E-02	0.3678250E-01	0.5111665	0.5161246	
	GAINS:	0.4441122	0.3830557	0.3220796	0.2660262	-0.7018843	-0.7119856	
DETECTOR 3	OFFSETS:	-0.5204000E-01	-0.2547210E-01	0.4418200E-02	0.3538790E-01	0.5161735	0.5215313	
	GAINS:	0.4359769	0.3830154	0.3234310	0.2610950	-0.6967177	-0.7073981	Band 1
DETECTOR 4	OFFSETS:	-0.5517190E-01	-0.2453140E-01	0.5966900E-02	0.3551150E-01	0.5164109	0.5217128	
	GAINS:	0.4524348	0.3899441	0.3277441	0.2672865	-0.7132953	-0.7241084	
DETECTOR 5	OFFSETS:	-0.5234010E-01	-0.2212130E-01	0.9521300E-02	0.3583130E-01	0.5118428	0.5172059	
	GAINS:	0.4387688	0.3762274	0.3148327	0.2621215	-0.6915625	-0.7024066	
DETECTOR 6	OFFSETS:	-0.5273780E-01	-0.2348360E-01	0.6308200E-02	0.3697390E-01	0.5138791	0.5190389	
	GAINS:	0.4451463	0.3857524	0.3253493	0.2631319	-0.7044545	-0.7149233	
DETECTOR 7	OFFSETS:	-0.6073620E-01	-0.2271010E-01	0.3033300E-02	0.2605410E-01	0.5262825	0.5280746	
	GAINS:	0.4265845	0.3569165	0.3083981	0.2050113	-0.6777646	-0.6811422	
DETECTOR 8	OFFSETS:	-0.5987640E-01	-0.2461550E-01	0.5089000E-02	0.3174230E-01	0.5226335	0.5248264	
	GAINS:	0.4380113	0.3698357	0.3124033	0.2608706	-0.6886329	-0.6926859	
DETECTOR 9	OFFSETS:	-0.5640410E-01	-0.2536150E-01	0.4667900E-02	0.3321290E-01	0.5210618	0.5228211	
	GAINS:	0.4360635	0.3753809	0.3166788	0.2608761	-0.6927794	-0.6962186	Band 2
DETECTOR 10	OFFSETS:	-0.5449460E-01	-0.2156940E-01	0.4683000E-03	0.2955910E-01	0.5222649	0.5237499	
	GAINS:	0.4286624	0.3648455	0.3221315	0.2657407	-0.6492716	-0.6921114	
DETECTOR 11	OFFSETS:	-0.6550580E-01	-0.2730500E-01	0.6767000E-03	0.2320630E-01	0.5333157	0.5350111	
	GAINS:	0.4249166	0.3550025	0.3037907	0.2625574	-0.6710319	-0.6752320	
DETECTOR 12	OFFSETS:	-0.6302850E-01	-0.2749620E-01	0.3275500E-02	0.2745940E-01	0.5290809	0.5307349	
	GAINS:	0.4304259	0.3638409	0.3061761	0.2606597	-0.6791260	-0.6821756	
DETECTOR 13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930820E-01	0.5128416	0.5165965	
	GAINS:	0.4018272	0.3369892	0.2839987	0.2294886	-0.6237667	-0.6305326	
DETECTOR 14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
	GAINS:	0.4104207	0.3501565	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR 15	OFFSETS:	-0.5909790E-01	-0.2957550E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5265452	
	GAINS:	0.4111196	0.3573549	0.2980555	0.2377676	-0.6489566	-0.6553429	Band 3
DETECTOR 16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5206682	
	GAINS:	0.4195329	0.3538085	0.2941260	0.2430468	-0.6521198	-0.6583961	
DETECTOR 17	OFFSETS:	-0.5729180E-01	-0.2311620E-01	0.1103720E-01	0.3702870E-01	0.5140637	0.5176793	
	GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6662350	
DETECTOR 18	OFFSETS:	-0.5744090E-01	-0.2168710E-01	0.9675900E-02	0.3629170E-01	0.5138956	0.5172043	
	GAINS:	0.4148560	0.3486704	0.2906130	0.2376407	-0.6427722	-0.6499080	
DETECTOR 19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	-0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	
	GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163138	
DETECTOR 20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409077	0.5428379	
	GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR 21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442040E-01	0.5398650	0.5425785	
	GAINS:	0.4301274	0.3632604	0.2965036	0.2340937	-0.6605740	-0.6654124	
DETECTOR 22	OFFSETS:	-0.7966350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452149	0.5466806	Band 4
	GAINS:	0.4643362	0.3869625	0.3213909	0.2572265	-0.7135698	-0.7163477	
DETECTOR 23	OFFSETS:	-0.7559100E-01	-0.3835500E-01	-0.6270600E-02	0.3437560E-01	0.5397990	0.5400425	
	GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7609597	-0.7698412	
DETECTOR 24	OFFSETS:	-0.7505930E-01	-0.3821360E-01	-0.3845400E-02	0.3395480E-01	0.5394332	0.5438306	
	GAINS:	0.5010801	0.4247016	0.3534583	0.2753091	-0.7727161	-0.7818332	

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Table B-8

Lamp B (Redundant) - Low Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5037410E-01	-0.1860890E-01	0.7132600E-02	0.3375870E-01	0.5132428	0.5148494	Band 1
	GAINS:	0.3994784	0.3610130	0.2936339	0.2446260	-0.6176971	-0.6408542	
DETECTOR 2	OFFSETS:	-0.4925510E-01	-0.1736830E-01	0.7233600E-02	0.3321810E-01	0.5142850	0.5138967	
	GAINS:	0.4148498	0.3535858	0.3063182	0.2563944	-0.6640353	-0.6671127	
DETECTOR 3	OFFSETS:	-0.5137230E-01	-0.1975810E-01	0.9809800E-02	0.3239550E-01	0.5137580	0.5151665	
	GAINS:	0.4072016	0.3481600	0.2929401	0.2507598	-0.6482158	-0.6508459	
DETECTOR 4	OFFSETS:	-0.4935090E-01	-0.1889950E-01	0.7552100E-02	0.3267990E-01	0.5133566	0.5148619	
	GAINS:	0.4148422	0.3563626	0.3055698	0.2576934	-0.6557859	-0.6686767	
DETECTOR 5	OFFSETS:	-0.5100680E-01	-0.1885540E-01	0.7868900E-02	0.3468700E-01	0.5129884	0.5162983	
	GAINS:	0.4120424	0.3511810	0.3005557	0.2498288	-0.6555641	-0.6580436	
DETECTOR 6	OFFSETS:	-0.4957090E-01	-0.1917420E-01	0.7952300E-02	0.3222310E-01	0.5134971	0.5150726	
	GAINS:	0.4107260	0.3529894	0.3014650	0.2553645	-0.6587762	-0.6617688	
DETECTOR 7	OFFSETS:	-0.5339620E-01	-0.2134640E-01	0.1028790E-01	0.4057520E-01	0.5102282	0.5136505	Band 2
	GAINS:	0.3722690	0.3180521	0.2645379	0.2133024	-0.5611859	-0.5669752	
DETECTOR 8	OFFSETS:	-0.5284440E-01	-0.2093220E-01	0.9033300E-02	0.3820700E-01	0.5113385	0.5151971	
	GAINS:	0.3760740	0.3214008	0.2700626	0.2200819	-0.5905040	-0.5971149	
DETECTOR 9	OFFSETS:	-0.5240090E-01	-0.1991050E-01	0.1153540E-01	0.3671770E-01	0.5103191	0.5137388	
	GAINS:	0.3780433	0.3219748	0.2677090	0.2242520	-0.5930367	-0.5989401	
DETECTOR 10	OFFSETS:	-0.5271350E-01	-0.2110650E-01	0.1046320E-01	0.4201610E-01	0.5090710	0.5128694	
	GAINS:	0.3762394	0.3220329	0.2678906	0.2137770	-0.5672270	-0.5927122	
DETECTOR 11	OFFSETS:	-0.5363690E-01	-0.2252990E-01	0.6717800E-02	0.3932520E-01	0.5122315	0.5158919	
	GAINS:	0.3609101	0.3099493	0.2587582	0.2066159	-0.5661186	-0.5721151	
DETECTOR 12	OFFSETS:	-0.5340150E-01	-0.2176900E-01	0.9007800E-02	0.3923330E-01	0.5113417	0.5155867	
	GAINS:	0.3669298	0.3141873	0.2628717	0.2124754	-0.5746930	-0.5817708	
DETECTOR 13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930620E-01	0.5126416	0.5165965	Band 3
	GAINS:	0.4018272	0.3389892	0.2839987	0.2294860	-0.6237607	-0.6305326	
DETECTOR 14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
	GAINS:	0.4104207	0.3501585	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR 15	OFFSETS:	-0.5909790E-01	-0.2957550E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5263452	
	GAINS:	0.4111196	0.3573589	0.2980555	0.2377670	-0.6489586	-0.6553429	
DETECTOR 16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5206604	
	GAINS:	0.4195329	0.3538085	0.2941260	0.2430986	-0.6521198	-0.6583961	
DETECTOR 17	OFFSETS:	-0.5729180E-01	-0.2311520E-01	0.1103720E-01	0.3762870E-01	0.5140637	0.5176793	
	GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6662356	
DETECTOR 18	OFFSETS:	-0.5744090E-01	-0.2168710E-01	0.9675900E-02	0.3829170E-01	0.5138956	0.5173063	
	GAINS:	0.4148560	0.3486704	0.2906130	0.2376407	-0.6427722	-0.6490080	
DETECTOR 19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	-0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	Band 4
	GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163130	
DETECTOR 20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409677	0.5428379	
	GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR 21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442060E-01	0.5398850	0.5425765	
	GAINS:	0.4301274	0.3632600	0.2985036	0.2340937	-0.6605740	-0.6650126	
DETECTOR 22	OFFSETS:	-0.7968350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452149	0.5460880	
	GAINS:	0.4643362	0.3869625	0.3213909	0.2572265	-0.7135698	-0.7163477	
DETECTOR 23	OFFSETS:	-0.7559100E-01	-0.3838500E-01	-0.4270600E-02	0.3437560E-01	0.5397980	0.5440425	
	GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7604597	-0.7898412	
DETECTOR 24	OFFSETS:	-0.7505930E-01	-0.3821360E-01	-0.3845400E-02	0.3385480E-01	0.5394332	0.5438306	
	GAINS:	0.5010801	0.4247016	0.3534583	0.2753091	-0.7727101	-0.7818332	

Multiplicative or additive modified values (M's and A's) have been developed to further adjust the radiometric calibration functions defined by the data provided in Tables B-3 through B-8. These values are intended to be applied as an additional step in developing gain and bias values from calibration wedge data. Tables B-9 and B-10 present the M and A values for each sensor operating mode.

B5. RADIANCE RANGE

The radiometric ranges which correspond to the calibration data presented in Tables B-3 through B-10 are defined in Table B-11.

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Table B-9
Multiplicative Modifiers

HIGH GAIN, LINEAR, LAMP A

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9910	1.0120	0.9250	1.0050	0.9070	1.0000	Band 4

LOW GAIN, LINEAR, LAMP A

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0003	1.0000	1.0000	1.0000	1.0000	0.9910	1.0120	0.9650	1.0050	0.9870	1.0090	Band 4

HIGH GAIN, COMPRESSED, LAMP A

Band 1	0.9939	1.0080	0.9903	0.9916	1.0140	0.9301	0.9938	1.0000	1.0050	0.9343	1.0090	0.9089	Band 2
Band 3	0.8870	0.8700	0.8530	0.8500	0.8560	0.0[illegible]30	[illegible].9910	1.0120	0.9950	1.0050	0.9370	1.0090	Band 4

LOW GAIN, COMPRESSED, LAMP A

Band 1	0.9310	0.9210	0.9100	0.9130	0.9100	0.9160	0.9900	0.9340	1.0050	0.9080	1.0200	1.0030	Band 2
Band 3	0.8370	0.8700	0.8630	0.8600	0.8550	0.8030	0.9910	1.0120	0.9050	1.0050	0.9370	1.0000	Band 4

HIGH GAIN, LINEAR, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LOW GAIN, LINEAR, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

HIGH GAIN, COMPRESSED, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LOW GAIN, COMPRESSED, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0300	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LEGEND:

Band 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	Band 2
Band 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	Band 4

Table B-10
Additive Modifiers

HIGH GAIN, LINEAR, LAMP A

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1360	−0.1500	−0.2020	−0.0430	−0.0300	−0.1760	Band 4

LOW GAIN, LINEAR, LAMP A

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1350	−0.1530	−0.2020	−0.0430	0.0200	−0.1760	Band 4

HIGH GAIN, COMPRESSED, LAMP A

Band 1	0.4003	−0.0369	0.2802	0.1141	−0.0369	−0.1408	0.4768	−0.0920	−1.2940	0.0070	1.0350	0.5394	Band 2
Band 3	−0.8480	−0.4840	0.8790	0.8200	0.0070	−0.1440	0.1330	−0.1530	−0.2020	−0.0430	0.0200	−0.1700	Band 4

LOW GAIN, COMPRESSED, LAMP A

Band 1	−0.1210	−0.0930	−0.0200	0.1560	0.1050	−0.0370	.0860	0.1200	−0.3110	−0.0750	0.2500	0.0260	Band 2
Band 3	−0.8480	−0.4040	0.8700	0.8200	0.0070	−0.1440	1360	−0.1530	−0.2020	−0.0430	0.0200	−0.1760	Band 4

HIGH GAIN, LINEAR, LAMP B

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 4

LOW GAIN, LINEAR, LAMP B

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 4

HIGH GAIN, COMPRESSED, LAMP B

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 4

LOW GAIN, COMPRESSED, LAMP B

Band 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 2
Band 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	Band 4

LEGEND:

Band 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	Band 2
Band 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	Band 4

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Table B-11
Radiometric Range of MSS Data

	Band	R_{min}*	R_{max}* At Launch	R_{max}* Postlaunch
Low Gain:	1	0.02	2.50	2.30
	2	0.04	1.80	1.80
	3	0.04	1.50	1.30
	4	0.10	4.00	4.00
High Gain:	1	0.01	0.80	0.80
	2	0.03	0.60	0.60

*R in milliwatt/cm^2/micron/steradian

APPENDIX C

TM DATA PROCESSING CONSTANTS

APPENDIX C

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TM DATA PROCESSING CONSTANTS

C1. MIRROR POSITION PROFILES

The prelaunch mirror position profiles are specified by fifth-order polynomials. The along- and across-scan polynomial profile coefficients for the various operating modes of the Landsat-4 scan mirror are provided in Table C-1. The across-scan profile is derived from the scan line corrector profile and scan mirror across-scan linearity. The forward scan profile polynomials start at scan-start and end at scan-end. The reverse profile polynomials start at scan-end and end at scan-start. Scan time has been normalized to 0.060743 second. A second-order correction, which is based on the first-half and second-half scan-time error, must be applied to these profiles (see Appendix E). This scan-error information is included in the TM wideband data.

The TM midscan pulse defines the instrument optical axis. In mirror-space, start- and end-scan pulses are at midscan -67157 microradian and +67175 microradian, respectively for SME-1 and -67171 microradian and +67195 microradian, respectively, for SME-2. The forward and reverse scan angle monitor pulses are nominally at the same angular location.

The scan-line corrector (SLC) velocity profile will be the same for forward and reverse scan mirror assembly scans and is also defined by a fifth-order polynomial. The best available information shows that all coefficients of the SLC fifth-order polynomial profile (SLC-1 and SLC-2) should be set to zero. The scan line corrector rates in object space are:

0.00966 rad/sec for SLC-1
0.00961 rad/sec for SLC-2

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Table C-1
Scan-Mirror Profile Along- and Cross-Scan
Data Summary for TM Protoflight Unit
(Landsat-4)

	Forward Polynomial Coefficients						Reverse Polynomial Coefficients						Scan Angles	
	a_0	a_1	a_2	a_3	a_4	a_5	b_0	b_1	b_2	b_3	b_4	b_5	Start to Mid (Fwd)	Mid to End (Fwd)
SME-1 SAM Mode Along Scan	3.6702e-7	2.1859e-3	2.6078e-1	1.1620e+1	2.2130e+2	1.4867e+3	6.001e-7	3.7036e-3	-3.2443e-1	1.2468e+1	2.2970e+2	1.4630e+3	67181	67175
SME-2 SAM Mode Along Scan	1.3649e-7	2.3408e-3	2.6000e-1	-1.1438e+1	2.1781e+2	1.4707e+3	4.0260e-7	3.0771e-3	-3.2899e-1	1.3183e+1	2.3549e+2	1.4930e+3	67171	67106
SME-1 Cross Scan	3.3356e-7	6.9110e-6	0.4933e-4	0.9008e-3	9.7717e-2	1.1003e-1	2.2008e-7	7.2290e-6	-1.7248e-3	1.3940e-2	2.7070e-2	1.1316e+0	N/A	N/A
SME-2 Cross Scan	2.7113e-7	2.7470e-6	1.0113e-3	-8.7369e-2	1.4040e+0	8.2887e+0	4.6600e-7	6.3702e-6	-1.0284e-3	1.0045e-2	6.2110e-1	4.4405e+0	N/A	N/A
Units	rads	rads/sec	rads/sec²	rads/sec³	rads/sec⁴	rads/sec⁵	rad	rad/sec	rad/sec²	rad/sec³	rad/sec⁴	rad/sec⁵	μrad	μrad

Note: SME is Scan Mirror Electronics
SAM is Scan Angle Monitor
N/A is Not Applicable

C.2 DETECTOR DELAYS AND BAND OFFSETS

The along-scan detector response data define the overall system delay for each detector and each scan direction. These data define the effective delays due to scan angle monitor delays, channel electronic delays and detector focal plane placement errors. Tables C-2 and C-3 give these detector delays in units of IFOV or 9.611 microseconds for the forward and reverse scan directions, respectively.

The cross-scan band center location errors relative to Band 4 are given in Table C-4. These location errors result from band placement during focal plane assembly, scan mirror misalignment and focal plane shifts resulting from mechanical vibration stresses.

C3. DRIRU AND ADSA TRANSFER FUNCTIONS

Table C-5 gives the DRIRU Transfer Function Model and the parameters applicable to Landsat-4. This transfer function defines the response of the DRIRU package to mechanical rotational inputs. The same transfer function is used for all axes.

Table C-6 gives the ADSA Transfer Function Model and parameters applicable to Landsat-4. These transfer functions define the response of the ADSA package to mechanical rotational inputs.

Table C-2
Forward Along-Scan Detector Delay in IFOV (9.611 μsec)

Detector	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6 (4 Detectors Only)	Band 7
1	1.305	1.315	1.245	1.195	1.390	4.900	1.335
2	1.240	1.475	1.205	1.185	1.240	4.900	1.200
3	1.260	1.270	1.225	1.185	[a]	4.900	1.305
4	1.235	[a]	1.180	1.130	1.225	4.900	1.200
5	1.265	1.300	1.245	1.185	1.315	0.0	1.315
6	1.240	1.235	1.250	1.175	1.300	0.0	1.200
7	1.235	1.270	1.240	1.180	1.240	0.0	1.305
8	1.205	1.195	1.265	1.205	1.370	0.0	1.220
9	1.240	1.280	1.165	1.225	1.310	0.0	1.270
10	1.220	1.210	1.190	1.190	1.240	0.0	1.190
11	1.225	1.265	1.205	1.195	1.325	0.0	1.305
12	1.225	1.230	1.245	1.185	1.220	0.0	1.140
13	1.275	1.310	1.235	1.245	1.315	0.0	1.285
14	1.215	1.250	1.265	1.235	1.270	0.0	1.135
15	1.235	1.310	1.275	1.215	1.285	0.0	1.315
16	1.255	1.265	1.280	1.230	1.250	0.0	1.115

[a] Failed Detector

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Table C-3
Reverse Along-Scan Detector Delay in IFOV (9.611 μsec)

Detector	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6 (4 Detectors Only)	Band 7
1	1.370	1.215	1.260	1.200	1.145	4.900	1.075
2	1.315	1.450	1.235	1.195	1.275	4.900	1.225
3	1.300	1.185	1.220	1.190	*	4.900	1.100
4	1.310	*	1.215	1.215	1.240	4.900	1.205
5	1.285	1.215	1.235	1.185	1.155	0.0	1.135
6	1.305	1.175	1.225	1.195	1.330	0.0	1.190
7	1.280	1.165	1.225	1.185	1.115	0.0	1.130
8	1.275	1.140	1.285	1.220	1.425	0.0	1.235
9	1.255	1.185	1.165	1.225	1.205	0.0	1.120
10	1.275	1.150	1.205	1.205	1.310	0.0	1.215
11	1.235	1.175	1.190	1.195	1.240	0.0	1.170
12	1.290	1.165	1.280	1.200	1.320	0.0	1.185
13	1.295	1.170	1.215	1.240	1.245	0.0	1.150
14	1.280	1.185	1.265	1.245	1.395	0.0	1.220
15	1.255	1.205	1.245	1.215	1.200	0.0	1.170
16	1.315	1.185	1.290	1.255	1.435	0.0	1.260

*Failed Detector

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Table C-4
Cross-Scan Band Locations
(Referenced to Band 4)

Band	Cross Scan Location Error In IFOV
1	-0.12
2	-0.10
3	-0.03
4	0.00
5	+0.18
6	+0.26
7	+0.12

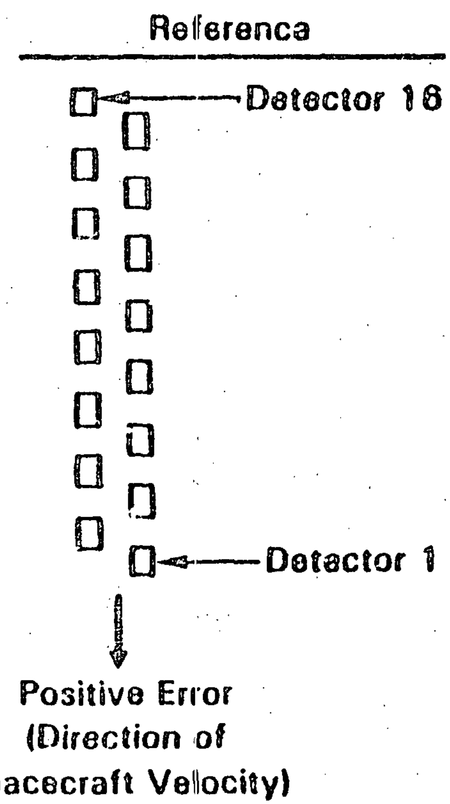

Table C-5
DRIRU Transfer Function
(all channels)

Transfer Function Model

```
H(S) = HNUM/HDEN
HNUM = AK*(1-P*S)
HDEN = (1 + 2*ZETA*S/WN + (S/WN)**2)*(1 + TAU*S)
```

Where,

```
W  = 2*PI*F
WN = 2*PI*FN
S  = CMPLX (0.0, WN)
F  = Frequency in Hertz
```

With,

```
FN = 2.2542
ZETA = 0.7057
TAU = 12.088e-3
P = 2.1977e-3
AK = 1.000173
```

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Table C-6
ADSA Transfer Function

Transfer Function Model —

H(S) = HNUM/HDEN

HNUM = = A5*S**5 + A4*S**4 + A3*S**3

HDEN = S**6 + B5*S**5 + ... + B1*S + B0

Where,

S = CMPLX (0.0, 2*PI*F)

F = Frequency in Hertz

SENSOR 1

A_3 = 4.619E6, A_4 = 5.360E5, A_5 = -3.501E2
B_0 = 7.138E8, B_1 = 9.433E8, B_2 = 2.120E8, B_3 = 1.609E7, B_4 = 6.028E5,
B_5 = 9.319E2

SENSOR 2

A_3 = 4.798E6, A_4 = 5.193E5, A_5 = -3.334E2
B_0 = 4.582E8, B_1 = 8.210E8, B_2 = 1.911E8
B_3 = 1.505E7, B_4 = 5.984E5, B_5 = 9.202E2

SENSOR 3

A_3 = 4.079E6, A_4 = 5.247E5, A_5 = -3.408E2
B_0 = 5.2398E8, B_1 = 8.606E8, B_2 = 1.634E8, B_3 = 1.455E7,
B_4 = 6.064E5, B_5 = 9.344E2

C4. TM RADIOMETRIC PARAMETERS (BANDS 1-5 AND 7)

Effective use of the TM internal calibration system is under investigation. At this time, radiometric corrections are being performed with fixed estimates of detector gain and bias. Table C-7 gives the reflective bands (Bands 1-5 and 7) gain and bias estimates for each detector. These estimates can be used to normalize the detectors to a common radiance range on output products.

Table C-7
Reflective Band Gain and Bias Data
(based upon prelaunch measurements)

GAIN IN COUNTS/(MILLIWATT/CM^2·SR)

DET	BAND 1	2	3	4	5	7
1	223.4243	101.4176	178.8467	78.1107	394.3920	558.7118
2	226.0388	100.7100	176.9300	77.0029	395.7365	551.2044
3	227.4471	99.4250	176.7333	78.4407	0.0000	554.6756
4	227.4443	101.0412	174.7583	77.1064	400.2100	554.7033
5	225.7571	101.0826	176.3000	76.9879	395.8100	554.8031
6	224.6543	101.5238	176.8500	77.8288	393.0355	550.0044
7	223.9729	99.8560	175.5933	78.8829	388.7386	565.1333
8	224.9743	100.2283	174.6600	77.4303	397.4680	545.8710
9	225.9567	100.1883	178.6450	77.3136	398.4355	556.4885
10	226.4600	100.4026	175.3433	80.3767	398.4010	543.6083
11	223.9814	99.2276	174.9200	76.5488	400.0380	551.0782
12	225.8300	99.4212	178.6100	77.6036	400.5005	555.6744
13	224.1014	100.5625	177.3050	78.7021	399.4700	548.8807
14	226.0114	101.0013	176.5533	77.8771	397.9426	564.0533
15	225.3514	101.6675	178.7083	76.8764	368.2050	549.0818
16	228.6483	98.8938	173.9783	77.0867	400.4330	557.8744
BIAS IN COUNTS	1	2	3	4	5	7
1	1.4442	1.3494	0.4644	1.3033	2.9003	3.7005
2	0.6445	0.6926	-0.0676	0.7286	2.5631	3.1116
3	0.8788	0.7948	0.2626	0.7258	0.0000	3.1213
4	0.8147	0.8008	-0.1630	0.8102	2.4894	3.1730
5	0.9142	0.7767	-0.0477	0.5460	2.6234	3.0163
6	0.7633	0.8940	-0.0242	0.7292	2.6494	3.2023
7	0.8373	0.6958	-0.0311	1.0042	2.8262	3.0297
8	0.8024	0.8879	-0.0888	0.8121	2.7027	3.1140
9	0.8766	0.7576	-0.1042	0.8705	2.6451	3.0808
10	0.7103	0.7144	-0.1332	0.4680	2.5439	3.1848
11	0.7846	0.7518	-0.1522	0.7245	2.6552	3.0557
12	0.7494	0.7179	-0.1462	0.5664	2.4920	3.2414
13	0.8167	0.7424	-0.2057	0.4317	2.7238	2.8838
14	0.6838	0.8305	0.0232	0.6828	2.5887	3.3247
15	0.9295	0.7253	-0.1282	0.4865	2.7628	2.8950
16	0.6057	0.8182	0.0202	0.7840	2.6807	3.3221
SPECTRAL BANDWIDTH IN MICRONS	0.7	0.8	0.06	0.14	0.20	0.27

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

The IIRV message in Figure D-1 shall be coded in USASCII. All data fields are right justified, with leading zeros added as needed. A positive sign (+) shall be indicated by a blank, and a negative sign (-) shall be indicated by a minus. The IIRV message shall contain spacecraft position and velocity for the given epoch time. Table D-1 contains IIRV message body data field explanations.

Vector epoch times will be provided four times daily, at 00:00, 06:00, 12:00 and 18:00 GMT.

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Line 1: _ _ _ _ _ CR CR LF LF (optional message text)

Line 2: G I I R V A R R R R CR CR LF LF

$\underbrace{\text{G I I R V}}_{\text{start of message}}$ A $\underbrace{\text{R R R R}}_{\text{destination routing indicator}}$

S S S S
I I I I

Line 3: V S T C C C C C B D N N N D O Y H H M M S S S S S C C C CR CR LF LF

Line 4: S X X X X X X X X X X X X S Y Y Y Y Y Y Y Y Y Y Y Y S Z Z Z Z Z Z Z Z Z Z Z Z

C C C CR CR LF LF

Line 5: S Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ Ẋ S Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ Ẏ S Ż Ż Ż Ż Ż Ż Ż Ż Ż Ż Ż Ż

C C C CR CR LF LF

Line 6: M M M M M M M M A A A A A K K K K S Ṁ Ṁ Ṁ Ṁ Ṁ Ṁ Ṁ C C C CR CR LF LF

Line 7: I T E R M Δ O O O O CR CR LF LF

$\underbrace{\text{I T E R M}}_{\text{end of message}}$ Δ $\underbrace{\text{O O O O}}_{\text{originator routing indicator}}$

Figure D-1. IIRV Message Body Format

Table D-1
IIRV ASCII TTY Message Body Explanation

Line	Characters	Explanation
1	-----	Optional message text.
2	GIIRV	Start of message (fixed).
	A	Alphabetic character indicating originator of message: blank = GSFC Z = WLPS E = ETR L = JPL W = WTR J = JSC P = PMR A = AFSCF K = KMR
	RRRR	Destination routing indicator. Specifies the site for which the message was generated. If for more than one station, this field should contain "MANY". [illegible]
3	V (Not Used)	Vector type: 1 = Free flight (routine). 2 = Forced (special update). 3 = Forced (no burn). 4 = Maneuver ignition. 5 = Maneuver cutoff. 6 = Reentry. 7 = Powered flight. 8 = Spare. 9 = Spare.
	S (Not Used)	Source of data: 1 Nominal planning. 2 Real-time. 3 Off-line. 4 Off-line mean.
	T (Always 1)	Transfer type: 1 Interrange. 2 Intercenter.
	C (Always 1)	Coordinate system: 1 Geocentric Greenwich Rotation. (all interrange vectors) 2 Aries mean of 1950. (all intercenter vectors)
	SIC (4 characters)	Support Identification Code. Landsat-D=1294, Landsat-D'=1419
	BB (Always 1)	Body number/VID (00-99).

Table D-1 (Continued)

Line	Characters	Explanation
3 (cont)	NNN	Counter number indicating vector transfer number on a per station per transmission basis.
	DOY	Day of year.
	HHMMSSSSS	Vector epoch in GMT with resolution to nearest millisecond.
	CCC	Checksum of preceding characters: 0 through 9 = Face value Minus (-) = 1 Plus (+) = 0
4	S	Sign character: (Minus: - Plus : blank)
	XXXXXXXXXXXX	X component of position (meters).
	YYYYYYYYYYYY	Y component of position (meters).
	ZZZZZZZZZZZZ	Z component of position (meters).
	CCC	Checksum of previous characters: 0 through 9 = face value. Minus (-) = 1. Plus (+) = 0.
5	S	Sign character.
	XXXXXXXXXXXX	X-velocity component.
	YYYYYYYYYYYY	Y-velocity component.
	ZZZZZZZZZZZZ	Z-velocity component.
		Note All velocity components are in meters/second with resolution to nearest 1/1000 meter/second.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1. Plus (+) = 0.

Table D-1 (Continued)

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Line	Characters	Explanation
6	MMMMMMMM	Mass of target (kilograms with resolution to 1/10 of kilogram) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	AAAAA	Average target cross-sectional area (meters squared with resolution to nearest square centimeter) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	KKKK	Drag factor (dimensionless) (two digits to left of decimal point). For intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	S	Sign character for mean motion rate. Positive sign denoted by a space or blank. Negative denoted by minus sign.
	.... MMMMMMM	Mean motion rate (revolutions/day) no digits to left of decimal point. Primarily intended for GSFC off-line support. Contains all zeroes when not used.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1 Plus (+) = 0
7	ITERM	End of message.
	0000	Originator routing indicator.

APPENDIX E
TM MIDSCAN CORRECTION SUMMARY

APPENDIX E
TM MIDSCAN CORRECTION SUMMARY

This appendix explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial. This is a simplified algorithm that does not include effects from spacecraft attitude deviations. Referring to Figure E-1, the upper curve illustrates an original smoothed profile that is normalized to the ideal scan time of 60743 μseconds. Its midscan value is defined as the profile (reference) offset angle ϕ_{fo}. This value is found during the data collection for the scan used when the original profile is taken. The second figure illustrates the actual profile for scan "i" in relation to the smoothed profile. The offset angle ϕ_{fi} is found from line length code. The "itn" scan differs from the smoothed profile by a parabola where the midscan amplitude is $(\phi_{fi} - \phi_{fo}) = \Delta_{fi}$. The calculation is performed at time T_{FH} where T_{FH} is the time of the first half scan. The lowest figure illustrates the original smoothed profile, the parabola, $\Delta(t)$, and the ground calibrated profile that is the parabola added to the original profile.

Figure E-2 gives the profile polynomial modification equations. The initial forward profile is a fifth-order polynomial with coefficients a_0 through a_5 defined for the ideal scan time. This initial profile is first adjusted to the actual scan time. The parabola for scan "i" is a second-order polynomial consisting of two terms, $a'_{1,i}$ and $a'_{2,i}$. The ground-calibrated profile is defined as the adjusted fifth-order power series with:

$$a_{1,i} = a_1 \left(\frac{t_I}{t_s}\right) + a'_{1,i} \text{ and } a_{2,i} = a_2 \left(\frac{t_I}{t_s}\right)^2 + a'_{2,i}.$$

- Take the center value between the 95 percent shoulders and 3 values on each side of the center value. Average the 7 values to determine the scan average.

- Average the scan averages.

- Blackbody gain function

  FBB = (CB-CS)/(NB-NS)

- Detector bias estimate

  Gain = 0.725 * FBB (Counts/(mW/cm^2/ster/micron)

- Detector bias estimate

  Bias = CS-(0.9*NS-0.19) * FBB (counts)

  Includes effects of internal TM radiators

- Applied corrections should set

  260°K to digital count 0

  320°K to digital count 255

  Scale linearly in radiance

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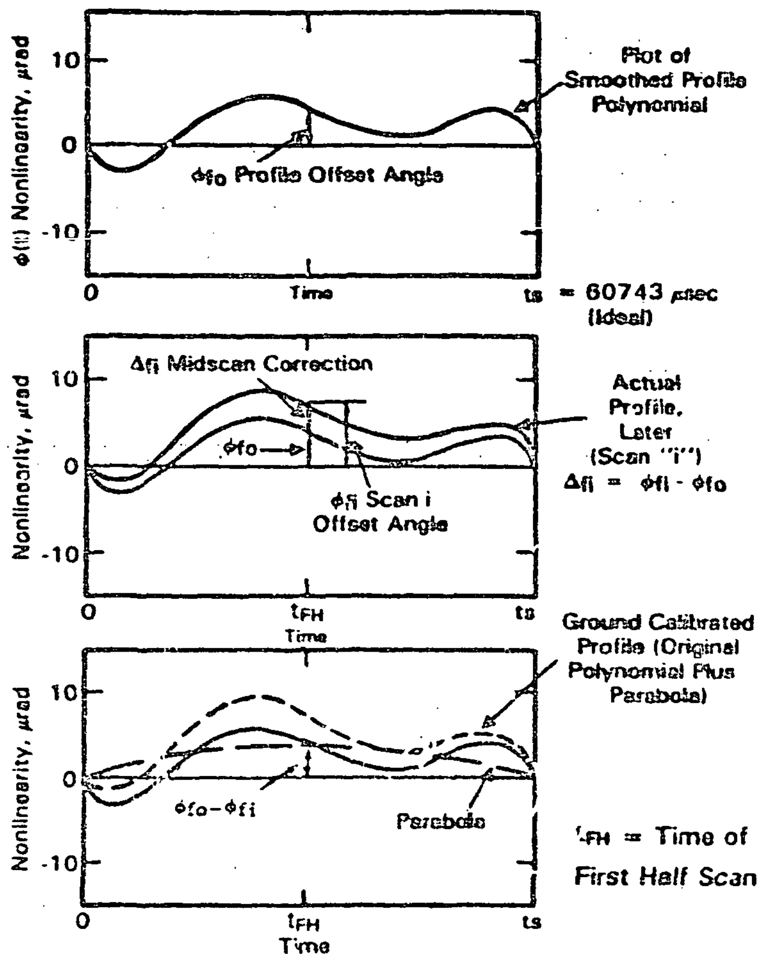

Figure E-1. Profile Polynomial
Modification Curves

- **Initial Smoothed Profile Polynomial**

  For Ideal Scan Time, $t_I = 0.060743$ Seconds

  $$\phi(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

- **Adjusted Smooth Profile Polynomial**

  For Actual Scan Time t_S:

  $$\theta_A(t) = a_0 + a_1\left(\frac{t_I}{t_S}\right) t + a_2\left(\frac{t_I}{t_S}\right)^2 t^2 + a_3\left(\frac{t_I}{t_S}\right)^3 t^3 + a_4\left(\frac{t_I}{t_S}\right)^4 t^4 + a_5\left(\frac{t_I}{t_S}\right)^5 t^5$$

- **Parabola Associated With Later Scan "i"**

  t_{FH} = First Half Scan Time for Scan "i"

  $$\Delta(t) = \frac{\Delta f_i}{t_{FH}(1 - t_{FH}/t_S)}\, t - \frac{\Delta f_i}{t_S t_{FH}(1 - t_{FH}/t_S)}\, t^2$$

- **Ground Calibrated Profile Polynomial:**

  $$a_{0,i} = a_0 \qquad a_{3,i} = a_3\left(\frac{t_I}{t_S}\right)^3$$

  $$a_{1,i} = a_1\left(\frac{t_I}{t_S}\right) + \left(\frac{\Delta f_i}{t_{FH}(1 - t_{FH}/t_S)}\right) \qquad a_{4,i} = a_4\left(\frac{t_I}{t_S}\right)^4$$

  $$a_{2,i} = a_2\left(\frac{t_I}{t_S}\right)^2 - \left(\frac{\Delta f_i}{t_S t_{FH}(1 - t_{FH}/t_S)}\right) \qquad a_{5,i} = a_5\left(\frac{t_I}{t_S}\right)^5$$

- **Δf_i is Obtained From Line Length Code**

Figure E-2. Profile Polynomial Modification Equations

The line length code, illustrated in Figure E-3, contains first-half and second-half scan errors E1 and E2, which are defined as R1-T1 and R2-T2, respectively, where R and T represent references and half-scan times. R1 equals 30371.4 μsec and R2 equals 30371.6 μsec (they total the ideal scan time, t_I = 60743.0 μsec). First-half scan error (FHSERR) and second-half scan error (SHSERR) have the units of 5 MHz clock periods (0.18845 μsec).

These represent the errors (in clock counts) from the references in clock counts (161164 and 161165), and negative values are transmitted in binary 2's complement format as indicated. Note the example of decoding, wherein midscan time errors E1 and E2 are found, after which first- and second-half scan time T1 and T2 can be determined.

When the actual wing mirror proportionality constant K_o and first- and second-half scan times are taken into account, the midscan offset angle ϕ_{fi} is as indicated. Finally, $\Delta_{fi} = \phi_{fi} - \phi_{fo}$ where ϕ_{fo} was previously identified from original profiles (Figure E-1). Δ_{fi} can then be applied (Figure E-2) to the original smoothed profile polynomial to obtain the desired ground-calibrated forward scan polynomial.

Similar computations yield the reverse midscan correction Δ_{ri} and the ground calibrated reverse scan polynomial.

The scan profile varies slowly and requires changing no more often than every 400 scans. The maximum expected ϕ_{fi} is 100 μradian. Significant active scan time variation (from the ideal 60743 μseconds) can be expected, especially when the MSS and TM instruments operate simultaneously.

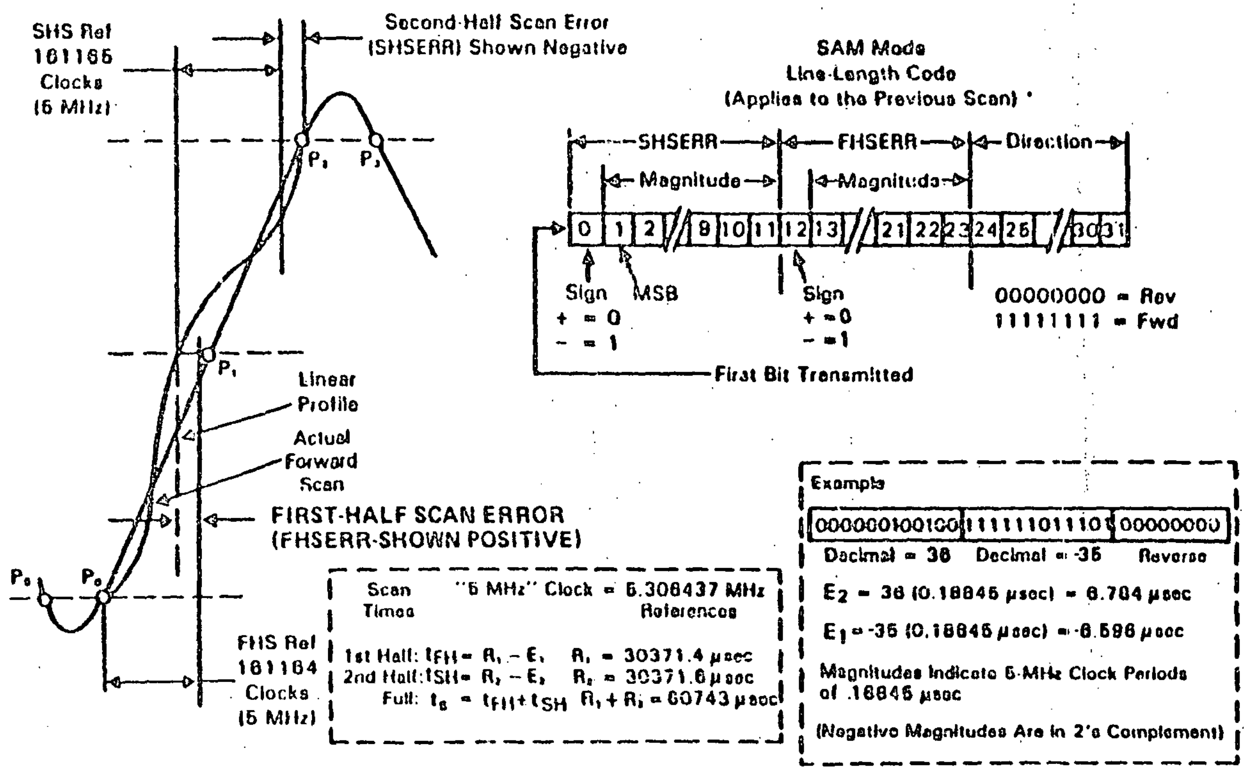

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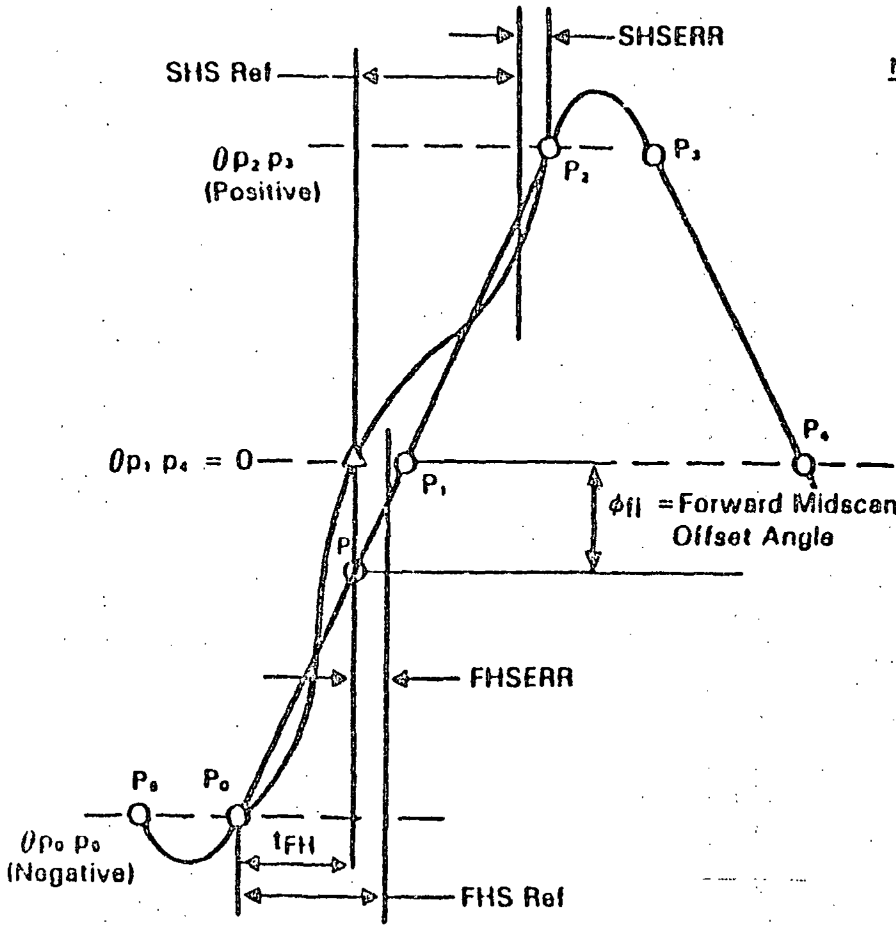
Figure E-3. Line-Length Coding (SAM Mode)



NOTE:
ANGLE $\theta_{P_0P_6}$ IS THE NEGATIVE OF THE START TO MID SCAN ANGLE DEFINED IN TABLE C-1 OF APPENDIX C.
ANGLE $\theta_{P_2P_3}$ IS THE MID TO END SCAN ANGLE DEFINED IN TABLE C-1 OF APPENDIX C.

Taking Into Account Active Scan Time (t_s) And SAM Wing Mirror Ratio (K_o)

$$\phi_{fl} = [t_{FH}(K_o - 1) + t_{SH}(K_o)] \left[\frac{\theta_{p_2p_3} - \theta_{p_0p_6}}{t_s}\right]$$

$$K_o = \frac{-\theta_{p_0p_6}}{\theta_{p_2p_3} - \theta_{p_0p_6}}$$

Forward Midscan Correction, Scan l

$$\Delta_{fl} = \phi_{fl} - \phi_{fo}$$

Figure E-4. Forward Offset Angle

Spacecraft attitude errors have the effect of moving the points P_0 through P_5 in inertial space. The effects of these angular motions can be compensated by using the outputs of Angular Displacement Sensors and the Attitude Control Gyros.

APPENDIX F

ALIGNMENT

APPENDIX F
ALIGNMENT

Figure F-1 shows the spacecraft coordinate system. Nominally all subsystems are aligned with the spacecraft coordinate system. The misalignment between the attitude control system, attitude sensors and the TM and the MSS instruments are defined in this appendix. The definition of the TM optical axis is given in Figure F-2. The MSS optical axis is similarly defined as:

Z-axis--The middle of the fiber optics face plate projected through the scan mirror. The scan mirror is at its one-half scan position.

X-axis--along the scan mirror pivot axis in the nominal direction of spacecraft flight

Y-axis--completes the right-hand rule.

The other axes of interest are the ADSA and DRIRU sensing axes and the attitude control reference axes. Attitude quaternion estimates and gyro drift estimates are defined in terms of the attitude control reference axes.

Table F-1 gives rotational matrices needed to convert from the DRIRU axes to the attitude control reference axes; from the attitude control reference axes to the TM optical and MSS optical axes; and from the ADSA axes to the TM optical axes. The coordinate transformations given in Table F-1 are based upon prelaunch measurements.

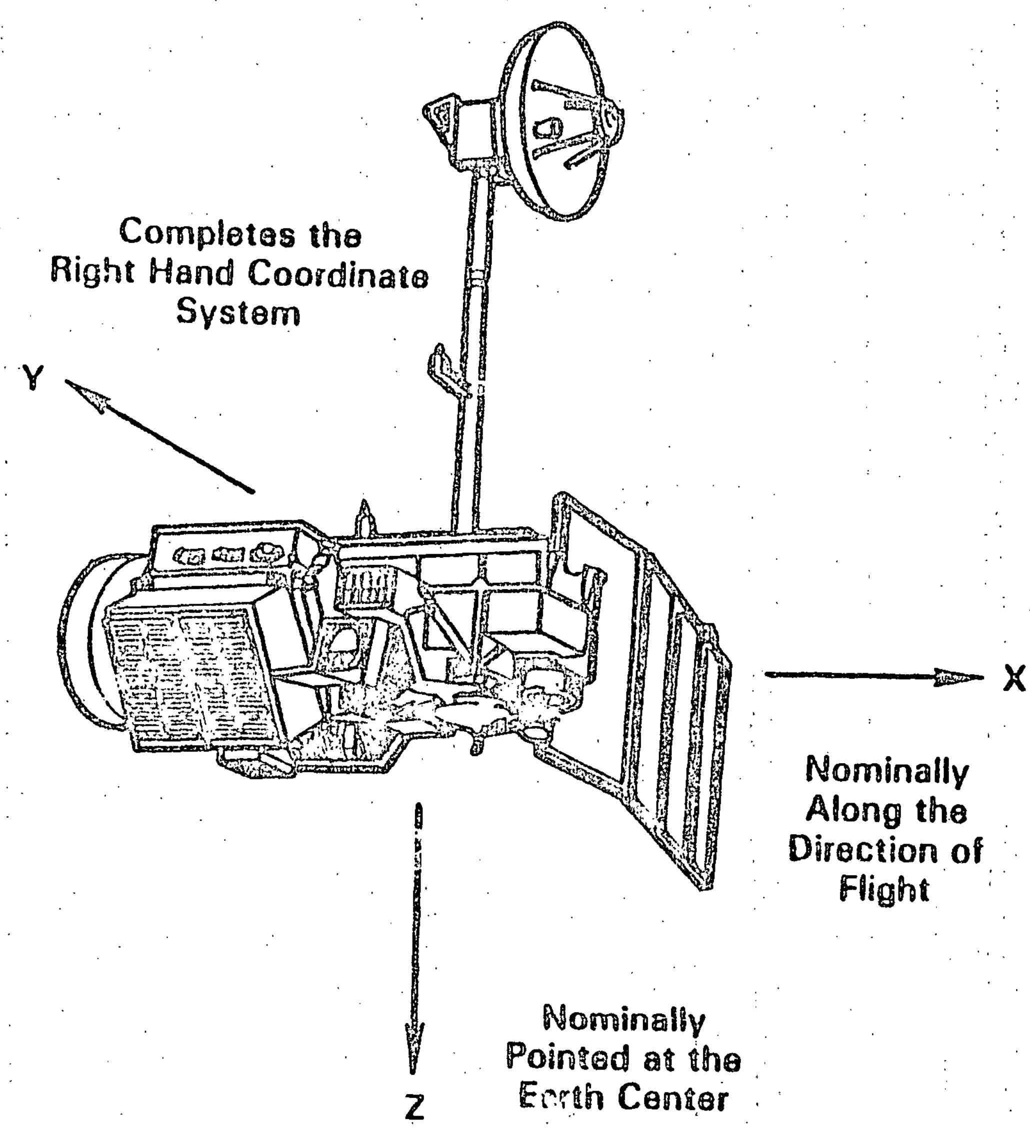


Figure F-1. Landsat-4 Coordinate System

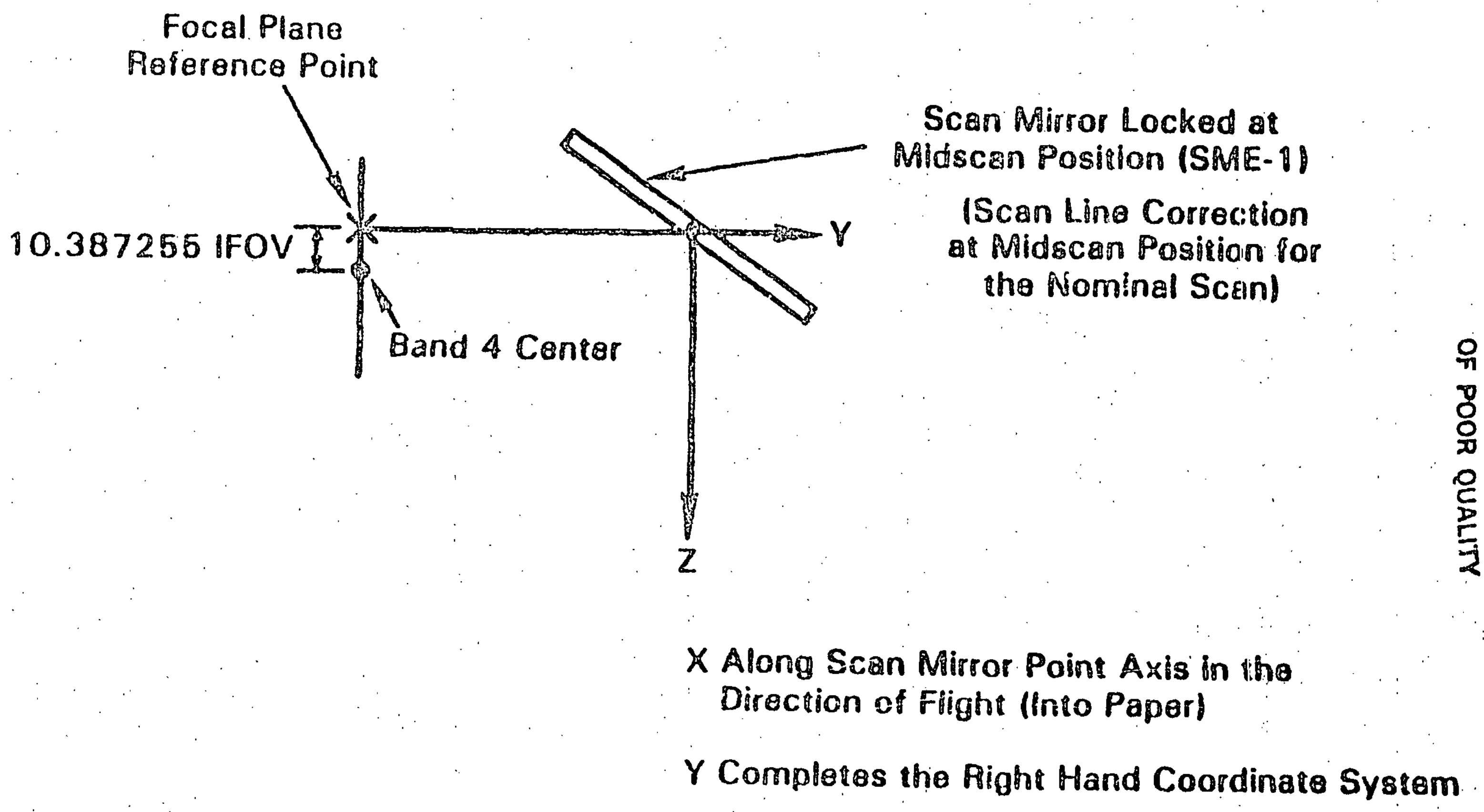


Figure F-2. TM Optical Axis Definition

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Table F-1
Coordinate Transtormations

$$\begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix} = \begin{bmatrix} 0.99999990 & 0.151127e-3 & 0.411108e-3 \\ -0.15111e-3 & 0.99999991 & -0.38839e-3 \\ -0.41114e-3 & 0.38833e-3 & 0.99999984 \end{bmatrix} * \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix}$$

Attitude Control Reference Axes — DRIRU Axes

$$\begin{bmatrix} X_M \\ Y_M \\ Z_M \end{bmatrix} = \begin{bmatrix} 1.0 & -0.049e-3 & -1.397e-3 \\ 0.049e-3 & 1.0 & 0.232e-3 \\ 1.397e-3 & -0.232e-3 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

MSS Optical Axes — Attitude Control Reference Axes

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & -0.596e-3 & 1.1464e-3 \\ 0.596e-3 & 1.0 & 0.431e-3 \\ -1.464e-3 & -0.431e-3 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

TM Optical Axes — Attitude Control Reference Axes

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & 3.09e-4 & -4.79e-4 \\ 3.48e-4 & 0.9407 & -0.339646 \\ 5.97e-4 & 0.339214 & 0.940574 \end{bmatrix} * \begin{bmatrix} X_{ADS} \\ Y_{ADS} \\ Z_{ADS} \end{bmatrix}$$

TM Optical Axes — ADSA Axes

Note: This transform is nonorthogonal and correctly represents ADSA sensing axis orientation.

APPENDIX G

TM THERMAL BAND RADIOMETRIC CALIBRATION

APPENDIX G

TM THERMAL BAND RADIOMETRIC CALIBRATION

The radiometric calibration procedure currently in use for TM Band 6 calibration is described below:

- Definitions

  CB = Average counts of the blackbody calibration data
  CS = Average counts of the shutter flag data
  NB = Effective spectral radiance of the blackbody
  NS = Effective spectral radiance of the shutter flag.

- Effective spectral radiance is the equivalent spectral radiance (mW/cm^2/ster/micron), uniform across the band, that would give the same TM response. It includes the spectral filter and detector spectral responses.

  At 90° K focal plane temperature
  N = (5.4656e-5*T-1.916e-2)* T + 1.771
  Where, T is temperature in degrees Kelvin.

- Temperature of blackbody and shutter flag are in payload correction data telemetry.

- Determination of CB = Average of blackbody calibration data (Hughes algorithm)

  - Find the location of the peak blackbody count.

  - Find the pulse shoulders on both sides of the peak that are 95 percent of the peak.